Foot modeling based on machine vision and social manufacturing research

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Abstract. With the development of productive forces, the manufacturing industry has developed from the "craft manufacturing" of agricultural society to mass production in industrial society, and then to mass customization manufacturing in the information society. In the future, manufacturing will be upgraded to "social manufacturing" in an intelligent society. The Internet of things, cloud computing, social networking, and other related to the most advanced technology will be introduced in the manufacturing process of the whole life cycle of society, aims to make every consumer can participate in the design, manufacture, service and consumption of this product in. In this paper, we discuss the future of highly customized high-end customization in social manufacturing - footwear customization.

On the basis of studying a great deal of related literature, this paper introduces the development of social manufacture of shoes and the socialized production of shoemaking industry, moreover, expounds the working principle of machine vision for 3D model reconstruction and carries out simulation experiments to ensure the correctness of the results.

Keywords: Social Manufacturing, 3D modeling rebuilding, Footwear, Machine vision.

1 Introduction

The rapid development of 3D scanning technology and 3D printing technology is changing our world, and its promotion of social manufacturing has also brought about an industrial revolution - relying on the Internet and Canadian manufacturing equipment to form a social manufacturing network. Social people fully participate in the whole life manufacturing process of the product through crowdsourcing, etc. to promote personalized, real-time, economical production and consumption patterns [1]. Footwear customization as a "mass customization" into a "social manufacturing" epitome, which contains information technology of four areas: information collection and transmission, virtual services, intelligent services, collaborative services.

First, use Three-dimensional scanning, RFID, Internet of Things and other technologies in the entire manufacturing process to obtain and share data and information.

Secondly, in the virtual service, use three-dimensional modeling technology and three-dimensional virtual technology to achieve custom information exchange between customer and designer.

Intelligent service is to optimize the intelligent customization process of manufacturing source.

Collaborative service refers to perform customization processes with the collaboration of designers, customers, manufacturers, and suppliers to maximize productivity.

The structure of the paper is as follows:

The first section describes what is the social manufacturing of the footwear industry, tells system structure and its core technology of the whole footwear industry social manufacturing. [2]

In the second section, the feasibility of three-dimensional reconstruction method based on machine vision for footwear customization is verified for the increasing demand of high precision model reconstruction.

The third section summarizes the research contents and achievements of the article, and puts forward the possible expectations and prospects for the further research work in this field.

2 Social manufacturing of the footwear industry

With the approach of "industry 4.0" and the development of cloud manufacturing and cloud computing, a model of customized production for customers - the socialized manufacturing model came into being. In social manufacturing, every consumer can participate in all stages of the product's life cycle, including product design, manufacturing and consumption. Use Internet of things, cloud computing and big data technology to form social manufacturing network system. On this basis, social manufacturing is bound to bring about revolutionary changes in the current manufacturing industry, the social manufacturing system in the future will be able to meet all the unique needs of all customers.

2.1 Introduction to social manufacturing

Social manufacturing can be defined as a personalized, real-time, intelligent manufacturing model. In addition to footwear industry, the social manufacturing model is also applicable to the apparel industry, mobile phones, furniture, photography, education and other personal fashion products. With the increasing demand for personalized customization, socialize manufacture is becoming more and more widely used and prospects. Among them, everyone can participate in social production and participate in "personalized needs to capture the entire product life cycle at any stage, personalized product design, personalized product manufacturing, and enjoy personalized service", through new information technology such as information network, social media, 3D printers and so on. The production model of social production has the following characteristics: [3] [4]

Every detail can be customized in depth, so called "a class of custom". through the personalized needs of customers to collect the full life cycle of the product to explore the potential market, personalized product design, personalized product manufacturing, and enjoy personalized service to improve customers' satisfaction.

The platform should support the full range of services for customers and manufacturers, as well as other roles in the model to make information flow and material flow unimpeded.

2.2 Social manufacturing system of footwear industry

Social manufacturing is based on mass customization. Social manufacturing is a new business model that takes full advantage of new support technologies and takes full account of customer needs.

System structure

. Footwear industry social manufacturing platform as shown, including the user layer, service layer, tool layer. [5] [6]

user layer.

Social manufacturing users include consumers, service providers (including designers), online retailers, shoe dealers and logistics distributors. The user layer provides a platform for human-computer interaction, providing a user interface.

service layer.

Users can participate in the socialization process of footwear industry. User-supplied requirements information and online retailers recommend appropriate options for users. Users can also choose to fully customize, independent design. The art resources, raw material resources, and plant resources used in the design can be fully shared in the social manufacturing cloud, and users can use them to design styles, provide materials, and process footwear. The production process and the distribution process can also be remotely controlled. For the after-sales service department, the service evaluation module can collect customer feedback information, continuous improvement services.

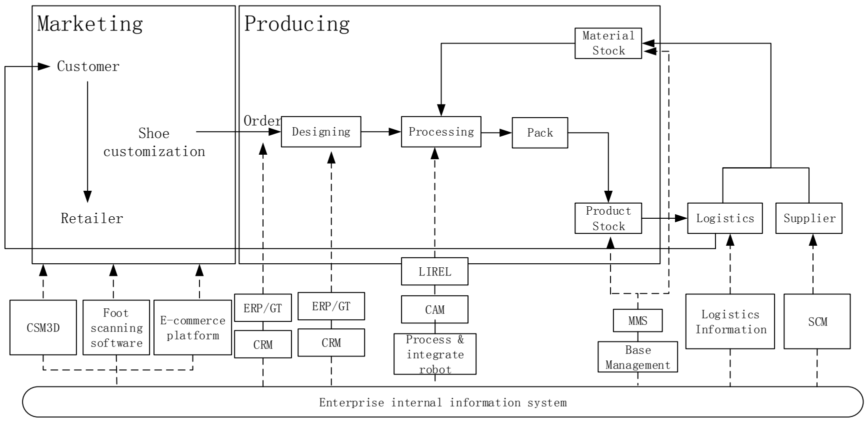

Fig. 1. The structure of modern social manufacturing system

tool layer.

The tool layer provides technical support for the realization of social manufacturing, including resource allocation and access technology, resource virtualization technology, human-computer interaction technology, network security technology and evaluation technology.

In addition, it also includes some of the actual physical manufacturing class resources, mainly: customer information, factory information, material information, design resources, modern logistics network, modern physical networking.

core technology.

Footwear social manufacturing system used in the core technology mainly for: information collection technology, information transmission technology, virtualization and service information technology, intelligent technology, collaborative management technology.

information collection technology.

Information collection and transmission to the cloud platform is the first step in achieving mass customization. Various manufacturing resources in the footwear production lifecycle include soft manufacturing resources and hard manufacturing resources. The process of collecting information includes customer information and enterprise information. We collect information through 3D scanning technology, RFID technology and sensor technology to facilitate resource management and virtualization.

Material supplier information includes information on global shoe material suppliers such as leather, fabric and sole suppliers, including their business qualification and material costs, material properties, and so on. The social manufacturing system will receive information on all qualified raw material distributors. In addition, the social manufacturing system also needs different styles of footwear designers around the world, footwear manufacturers information. The above information is based on RFID technology, intelligent sensor technology, GPS technology, laser scanner acquisition technology to achieve.

information transmission technology.

After collecting the information of all the participants in the footwear supply chain, all the information will be safely transferred to the social manufacturing platform. Information will be added to the cloud, through the Internet of things technology to achieve interconnection, identification, manufacturing resource perception. The main technologies include: communication network, 3G / 4G network, GPRS network, broadcast network, NGB wide area network.

virtualization and service information technology.

The information collected through the above information collection technology and information transmission technology will be put into the virtual world, making it more conducive to control the supply chain, make full use of production resources and ensure the full participation of customers. This process requires the use of virtualization and service technology.

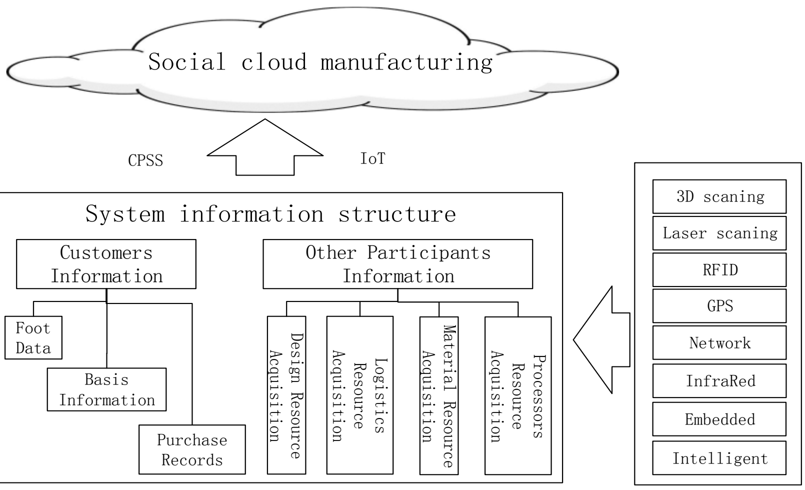

Fig. 2. Technical structure of social manufacturing system

intelligent technology.

The intelligentization and manufacturing intelligence in the production process will be reflected in the process of description, recommendation, matching, transaction, execution, scheduling, settlement, evaluation and so on in the social manufacturing system. For example, when choosing shoes for raw materials, people only need to enter the relevant information (price, shoe type), the system will recommend the most cost-effective materials, the best suppliers and the approximate price.

collaborative management technology.

In the social manufacturing cloud model, the design and processing of a product is no longer a business can be done alone, it requires the global participation of different enterprises to complete. Collaborative management system is both an efficient and collaborative work platform based on the Internet, and it is also an excellent collaborative management system. It uses advanced computer technology, and then into the collaborative management concept, through the same platform, the same authority of the staff can work together. In the practical application can effectively improve the efficiency of business operations. Mainly include: collaborative products business, product life cycle management, office automation.

3 Machine vision technology used in footwear society manufacturing

Three-dimensional model reconstruction using machine vision is an important technology in computer vision technology. It is also the core of machine vision. It mainly studies how to restore depth information of the object of a collected image by analyzing and deposing one or more images. In the machine vision stereo reconstruction technology, binocular vision based on two images technology is a hot topic in recent years. Binocular stereoscopic vision is imitating the human eye structure, to reproduce the actual process of human stereoscopic perception, calculate different images in the same object pixel position deviation through simple geometric principles, obtain the depth of information of target object. Because such methods do not require a specific instrument, and the instrument cost is low, the expected calculation is not large, the degree of automation is high. [7] [8]

Compared with the machine vision modeling under the analogous large scene, this method has the uniqueness for the specialized problem. Because of the high accuracy of footwear customization, a binocular vision modeling with reference is proposed in this method. And because of the particularity of the binocular vision technique, the calibration of the camera also uses a combination of stratified calibration and Tsai two-step calibration, and is expected to improve accuracy.

3.1 The use of binocular vision for the establishment of three-dimensional model

The advantages of the laser scanning type three-dimensional model described above have high accuracy and good model integrity, but the shortcomings are also obvious, because of its "industrial 4.0" "Made in China 2015" and other manufacturing industry changes in the status quo, The past desktop high-precision scanner has not meet the trend of the times, the future is in urgent need of low cost, high efficiency, everyone can easily achieve high-precision data acquisition technology. The technology of image acquisition, data acquisition and then achieve three-dimensional reconstruction using binocular vision technology just to meet this demand.

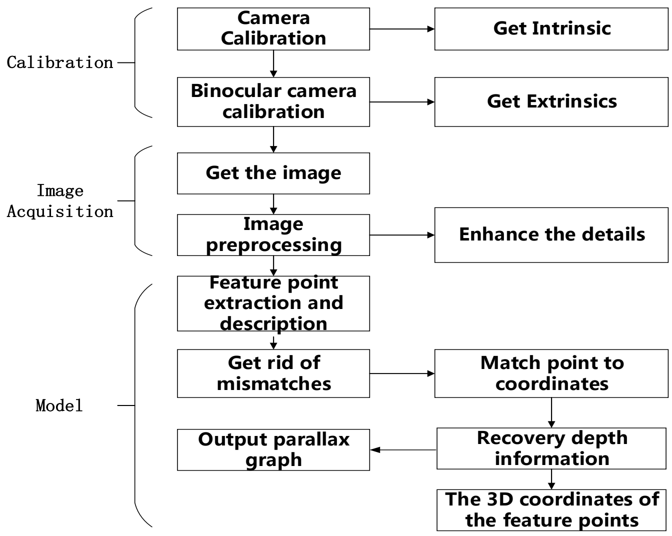

Fig. 3. A flow chart of 3D reconstruction based on machine vision technology

3.2 Camera calibration

Most of these technologies are currently used for 3D reconstruction of large-sized objects, and there is no systematic application in the social manufacturing system. However, due to the low cost and portability of such methods, such methods are in the trend of global industrial change can be efficient and low-cost for customers required products to achieve data acquisition and three-dimensional model reconstruction.

In the three-dimensional machine stereoscopic vision system, the target object's position, shape, attitude and other physical information are dependent on the camera to take pictures. The camera calibration says that the internal optical geometric characteristics of the camera being used (the internal reference) and the coordinates of the two cameras in the three-dimensional world (the external reference) are checked by a set of information knowed pictures (include the image coordinates and the reference point coordinates). Through the lens, a three-dimensional object in the space will be mapped into an inverted image and be perceived by the sensor.

Ideally, the optical axis of the lens should pass through the middle of the image. However, the actual camera quality and the problem of installation accuracy, there is always error, this error needs to use a set of parameters to correct, this group of parameters is called internal parameters.

In the ideal case, the size of the reduction ratio of the camera in the horizontal axis (x direction) and the vertical axis (y direction) should be the same, but in fact, the lens quality, sensor (CCD or CMOS) quality varies, if the lens is not perfect circles, or pixel-sensitive points on the sensor are not perfectly aligned squares, which can lead to inconsistencies in the reduction of the horizontal and vertical axes. This asymmetry error requires two parameters to correct.

Ideally, we think that the lens strictly follows the principle of projective transformation (that is, the straight line in the three-dimensional space is still a straight line through the lens), but in fact, the lens accuracy is not high enough, cannot be so perfect, after the lens mapping, originally a straight line will have a certain degree of bending, where a set of distortion parameters to correct this deformation.

The above three correction parameters in accordance with certain rules into a matrix called the camera's internal parameters.

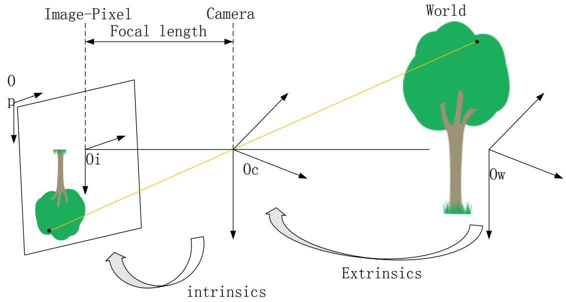

Fig. 4. The meaning of intrinsics and extrinsics

The extrinsic reference obtained by the camera calibration is indeed an exact value, but the acquired camera interior parameter is an approximation of the optical properties of the camera. The calibration of each camera is only an approximation for the cameras in the sampling space. Therefore, in view of the particularity of foot modeling in paper, we choose 20cm distance to calibrate to obtain higher accuracy.

The calibration of the camera is the study of the imaging transformation. The imaging transformation involves the transformation between different coordinate systems: pixel plane coordinate system（u, v）, image physical coordinate system（x, y）, camera coordinate system（Xc, Yc, Zc） and world coordinate system（Xw, Yw, Zw）. among them, [10] [11]

Pixel plane coordinate system（u, v）, also known as the computer frame memory system, which in the computer by a matrix of M rows and N columns describes an image, the value of each element (pixel) in the matrix is the gray value of the image of the location.

The image physical coordinate system（x，y） makes up the defect of the pixel plane coordinate system has no physical unit to represent the pixel position, the actual measurement size of each pixel in the x (u) axis and y (v) axis direction is dx, dy. So, where any of the pixels in the digital image satisfies the following relation in the (u, v) and (x, y) coordinate systems (where dx-1, dy-1 is called the scale factor):

$$u = \frac{x}{dx} + u_0$$
$$v = \frac{y}{dy} + v_0 \qquad (1)$$

Will be used in homogeneous coordinates in matrix form as:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ \frac{1}{dy} & 0 & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \quad or \quad \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} dx & 0 & -u_0 dx \\ 0 & dy & -v_0 dy \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \tag{2}$$

Camera coordinate system (Xc, Yc, Zc), the Xc, Yc axis in the coordinate system are parallel to the x, y axis in the image, the Zc axis is the camera axis, perpendicular to the image plane. The intersection of the plane xy is the origin of the image coordinate system [10]. The intersection of the Zc axis and the plane Xc and Yc is the optical center O of the camera. The rectangular coordinate system composed of the point O and the Xc, Yc and Zc axes is called the camera coordinate System.

The world coordinate system (Xw, Yw, Zw), the coordinate system used to describe the location of any object, by the Xw, Yw, Zw axis composition, also known as the absolute coordinate system [11]. The camera coordinate system and the world coordinate system can be described its conversion mode by the rotation matrix R, translation vector T. [12] [13]

$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} = \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = L_W \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{3}$$

R is the eye (3); T is the 3-row and 1-column translation vector; 0T = (0,0,0) T; LW is a 4 × 4 reduced matrix.

Camera model.

The relationship between the pixel plane coordinate system (u, v) and the camera coordinate system (Xc, Yc, Zc) can be obtained from the camera model:

$$\begin{Bmatrix} \frac{x}{f} = \frac{X_c}{Z_c} \\ \frac{y}{f} = \frac{Y_c}{Z_c} \end{Bmatrix} \text{ or } \begin{Bmatrix} Z_c \cdot x = f \cdot X_c \\ Z_c \cdot y = f \cdot Y_c \end{Bmatrix} \tag{4}$$

Will be used in homogeneous coordinates in matrix form as:

$$Z_c \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} \tag{5}$$

The above relationship is:

$$Z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = L \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = \begin{bmatrix} l_1 & l_2 & l_3 & l_4 \\ l_5 & l_6 & l_7 & l_8 \\ l_9 & l_{10} & l_{11} & l_{12} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{6}$$

Expressed in the form of an equation:

$$\begin{aligned} u &= (l_1X + l_2Y + l_3Z + l_4) / Z_c \\ v &= (l_5X + l_6Y + l_7Z + l_8) / Z_c \\ Z_c &= l_9X + l_{10}Y + l_{11}Z + l_{12} \end{aligned} \tag{7}$$

Will Zc into the formula 7:

$$\begin{cases} u = \dfrac{l_1X + l_2Y + l_3Z + l_4}{l_9X + l_{10}Y + l_{11}Z + l_{12}} \\ v = \dfrac{l_5X + l_6Y + l_7Z + l_8}{l_9X + l_{10}Y + l_{11}Z + l_{12}} \end{cases} \tag{8}$$

Where l_1 to l_{11} are 11 coefficients associated with u0, v0, f, Kx, Ky, U, X, J and XS, YS, ZS; they together determine the imaging characteristics of the camera.

X0, y0, f called the camera within the unit; U, X, J and XS, YS, ZS known as the camera outside the bit.

If we know that more than six space points (X i, Y i, Z i) and its coordinates (u i, v i) can be explained L1, L2, ..., L11by the above formula; to get the camera parameters[14]. If you know the parameters of two or more cameras L1, L2, ..., L11; according to the spatial point's coordinates (xj, yj) in the camera, from the above formula can be resolved space coordinates（X，Y，Z）. The process of determining L1, L2, ..., L11 is called calibration. Known (xj, yj), the process of solving (X, Y, Z) is called reconstruction. Will pass on the above points and points out:

$$\begin{aligned} l_1X + l_2Y + l_3Z + l_4 - l_9uX - l_{10}uY - l_{11}uZ = l_{12}u \\ l_5X + l_6Y + l_7Z + l_8 - l_9uX - l_{10}uY - l_{11}uZ = l_{12}u \end{aligned} \tag{9}$$

From the above equation, we can see that there are six or more known points in space and their image coordinates to obtain the L matrix. In the normal calibration work, the feature points on the calibration plate will be far more than six, which makes the number of equations far more than the number of unknowns, we can use the least squares method to filter the data, making the error as much as possible small.

We assume that the known calibration points have N, and we can write 2N equations of the above equation, a matrix of which is expressed as:

$$AL = U \tag{10}$$

Where L is: ［11，12，13，14，15，16，17，18，19，110，111，112］^{T};
A is:

$$\begin{bmatrix} X_1 & Y_1 & Z_1 & 1 & 0 & 0 & 0 & 0 & -u_1X_1 & -u_1Y_1 & -u_1Z_1 \\ 0 & 0 & 0 & 0 & X_1 & Y_1 & Z_1 & 1 & -v_1X_1 & -v_1Y_1 & -v_1Z_1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ X_n & Y_n & Z_n & 1 & 0 & 0 & 0 & 0 & -u_nX_n & -u_nY_n & -u_nZ_n \\ 0 & 0 & 0 & 0 & X_n & Y_n & Z_n & 1 & -v_nX_n & -v_nY_n & -v_nZ_n \end{bmatrix} \tag{11}$$

U is：［u1L12，v1L12，… unL12，vnL12］^{T}

In the matrix U, L12 (l12) has no effect on the other values, so that it can be any value, then we make it a value of 1. So that there are only 11 unknowns in the vector L, after solving the L, you can reverse out of the internal and external parameters of the camera through the L. [15]

3.3 Experimental results

The camera used in this test using Sony IMX105PQ sensor, 1 / 3.2-inch color CMOS, the camera total pixels are 8.1 million pixels, effective pixels are 7990272 pixels. Fixed F2.4 aperture, the lens equivalent focal length is 35mm. [16]

The calibration plate is generated by MATLAB, as shown in the figure, displayed on the LCD screen, this digital calibration plate has high flatness, can clearly obtain the feature points after shooting pictures, eliminating many image processing steps. Figure x is a photograph of 10 secondary calibration plates.

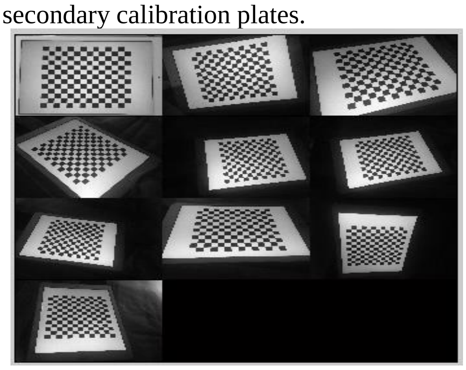

Fig. 5. Photo to test

The following figure shows the two detected angles (cross) and the grid point (circle) of the re-projection, the arrow in the figure is the existence of corner detection error point and its offset direction.

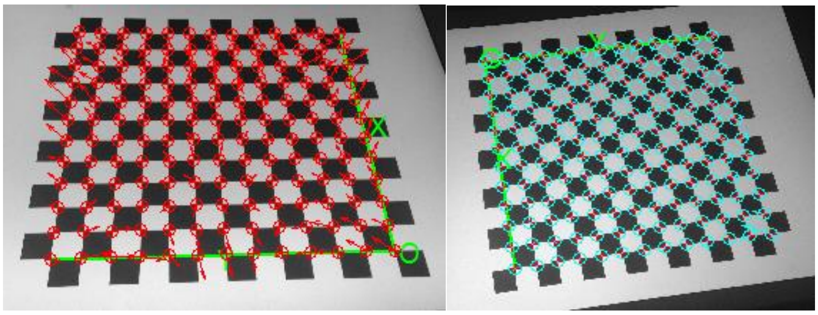

Fig. 6. Angular point calibration

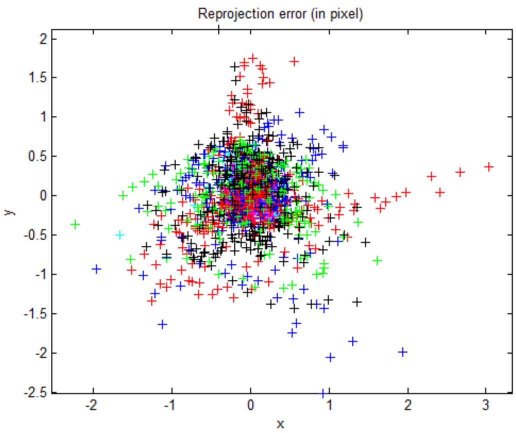

Fig. 7. The calibration of ten pictures

Points of the re-error are also marked out by the cross of different colors in the figure. [17]

The following figure shows the world center coordinate system and the camera center coordinate system diagram. The left graph shows the calibration with the origin of the calibration plate; the right graph is the calibration with the origin of the camera.

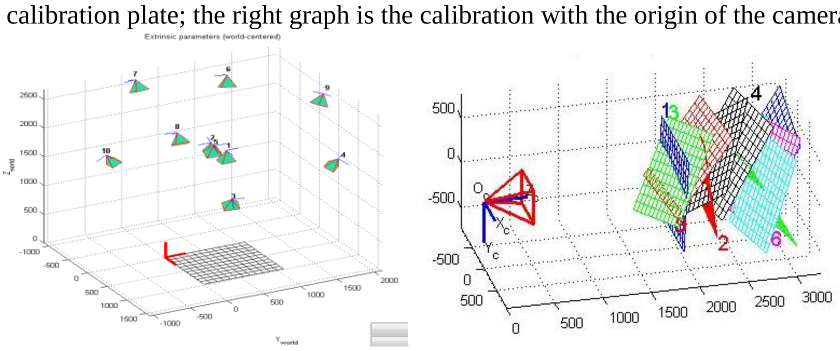

Fig. 8. Calibration result schematic

4 Conclusion

With the "Industrial 4.0" and cloud manufacturing approaching, this paper presents a socialized manufacture mode for the footwear industry customized manufacturing. In social manufacturing, each consumer can participate in all stages of the product life cycle, such as product design, manufacturing and consumption. Through the Internet of Things of manufacturing industry, cloud computing and large data, social manufacturing network system is formed and achieved. With the increasing demand for personalized customization, socialized manufacturing is becoming more and more widely used and prospects. This paper predicts the possible changes in the future manufacturing industry, and puts forward some countermeasures to the reform of the footwear industry in China, and proves the feasibility of a three-dimensional reconstruction method based on machine vision for the customization of footwear. The experiments show that in the footwear social manufacturing process based on the machine vision technology, each of the two related pictures can obtain more than ten information of characteristics matching successfully, this method has great application prospects.

Acknowledgments

We would like to acknowledge support in part from the National Natural Science Foundation of China under Grants 61233001, 71232006, 61533019, 61773381 and 61773382; Chinese Guangdong's S&T project (2015B010103001, 2016B090910001), Dongguan’s Innovation Talents Project (Gang Xiong).

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