Application of 3D CAD in the Design of Inspection and Planning System of Intelligent Three-coordinate Measuring Machine

Jin Guang and Fan Li

Zhengzhou railway vocational &technical college, Zhengzhou, Henan 451460, China, jguang80@sina.com

Corresponding author: Jin Guang, jguang80@sina.com

Abstract. Computer aided inspection planning based on CAD coordinate measuring machine is the basic key technology, which occupies a very important position in the quality system. Nowadays, the research of integration technology has made a lot of achievements, but the research on information integration of system and system lags far behind the information integration of machining. How to use the part information and measurement-related knowledge provided by the product model to automatically generate optimal testing procedures and testing instructions for use is the basic task of the oriented intelligent system. This paper aims at the development of intelligent CMM inspection planning system based on 3D, from the overall analysis and design of the system to the extraction of detection geometric information, sampling planning, detection path planning and automatic generation of quack measurement program and other related key technologies will be studied. This paper briefly analyzes the relevant factors that determine the number of sampling points and summarizes the point requirements for the distribution of sampling points, and in view of the shortcomings and limitations of various methods of sampling point distribution on the general surface, a sampling strategy with adaptive step size is proposed, which solves the problem of sampling planning on the general surface. In the specific implementation of sampling planning, it is divided into two ways: edge-based and face-based geometric element measurement and sampling. Considering the requirements of distribution points, specific sampling algorithms are designed respectively, focusing on the analysis of the differences between edges and faces.

Keywords: 3D reality; CAD; inspection and planning system; intelligent three-coordinate
DOI: https://doi.org/10.14733/cadaps.2021.S3.141-152

1 INTRODUCTION

In order to improve the competitiveness of enterprises and improve and guarantee product quality, it is necessary to carry out inspection of product parts. Before the correct implementation of part inspection, it is particularly important to make a reasonable inspection plan for the parts [1]. With the development of China's machinery manufacturing industry and advanced manufacturing technology, the demand for product quality control is getting higher and higher, and the rapid, high-precision, automatic and intelligent detection of products has become more and more important. The traditional manual method is time-consuming and non-standard, and its accuracy and consistency are difficult to guarantee, which seriously affects the implementation of parts inspection activities, while the introduction costs of foreign commercial systems by Yang et al [2]. The inspection planning system of coordinate measuring machine based on CAD can automatically generate the inspection plan and the measurement program under the guidance of the CAD model of the workpiece [3]. The introduction of CAD system in the inspection planning system is the key to realize the system and integration, and it is also the basis of the automation and intelligence of the system. The intelligent level of the system and the optimization degree of the inspection planning directly determine that the intelligent level of the system supports the industry standards is the premise of good compatibility and versatility of the system. These are the contents that should be considered in the development of an intelligent CMM inspection planning system. At present, Bergamasco et al research on system development and technology, which is still in the stage of development, and these three aspects of system development are still relatively backward compared with foreign countries [4]. Therefore, it is particularly important and meaningful to independently develop a set of intelligent CMM inspection and planning system based on 3D CAD [5].

In order to improve the measuring efficiency and automation level of the measuring machine, it is necessary to group the measuring geometric features, so that the probe of the measuring machine can measure as many geometric features as possible under the same probe type and probe angle direction [6]. In the past, the detection process can only be detected by human visual observation, relying on the detection experience to detect the geometric features manually [7]. When the parts are more complex and contain more testing items, multiple probes or probe angles are often used, so it is difficult to reasonably plan the detection sequence of geometric features to be tested simply by manual experience. The polychromatic set theory is applied to solve the optimization problem of part inspection, as shown in Figure 1, by grouping the features with the same probe type, the same probe angle and the same dependent detection plane, and the selection of the grouping is only stored in the form of contour Boolean matrix, which provides a new way to establish the knowledge base of parts inspection planning. Through the coloring logic operation in the polychromatic set, the detection scheme of the part is obtained. The selection of probe mainly includes the selection of probe type and probe angle direction. Lyu measured the parts, the type of the probe is mainly selected according to the size, position, shape and precision requirements of the items to be tested, and the angle direction of the probe is selected according to the touchability of the items to be tested [8]. When the size information, shape information, item type and tolerance accuracy of the part are read from the database, the type of probe is determined according to the inspection information of the part, such as the size of the ruby ball, the length of the lengthening rod, the shape of the probe and so on. According to the geometric features to be tested, the probe type, the probe angle and the contour Boolean matrix attached to the detection plane, the items to be tested are clearly displayed to the user [9]. Based on the principle of probe replacement and the number of angle transformation, the constraint model of global path planning of parts to be tested is established by using polychromatic set theory. The probe type, probe contact angle and attachment detection plane selected for the geometric feature measurement of the parts to be tested are described intuitively, and the constraint requirements can be easily added according to the difference of the parts [10]. On the basis of this model, genetic algorithm is used to sort the measured geometric features, and how to improve the speed of convergence to the optimal solution is discussed while obtaining the effective solution [11,12].

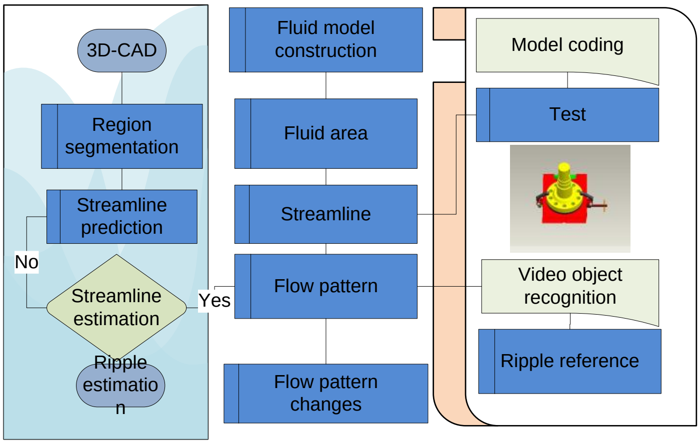

Figure 1: Polychromatic set theory.

At present, the setting of empty walking and non-interference points in the research of obstacle avoidance is mostly based on the position of individual measuring points, while ignoring the direction of the probe, which is actually very dangerous. Because some position points are impossible for the probe to reach in the current direction. Based on this, the probe direction will be one of the main factors to be considered in the collision avoidance research in this paper. This paper aims at the development of intelligent CMM inspection planning system based on 3D, from the overall analysis and design of the system to the extraction of detection geometric information, sampling planning, detection path planning and automatic generation of quack measurement program and other related key technologies will be studied. This paper briefly analyzes the relevant factors that determine the number of sampling points and summarizes the point requirements for the distribution of sampling points, and in view of the shortcomings and limitations of various methods of sampling point distribution on the general surface, a sampling strategy with adaptive step size is proposed, which solves the problem of sampling planning on the general surface. In the specific implementation of sampling planning, it is divided into two ways: edge-based and face-based geometric element measurement and sampling. Considering the requirements of distribution points, specific sampling algorithms are designed respectively, focusing on the analysis of the differences between edges and faces. The experimental results of sampling planning show that the step size adaptive resampling method based on regular uniform distribution is not limited by whether the surface is continuous or not, and can well adapt to the surface shape features, while uniformly distributing the sampling points as far as possible. Avoid the discontinuous area on the surface, which has a good adaptability to the surface of all kinds of complex conditions. It makes up for the lack of homogenization of random sampling and the requirement of complete and continuous surface based on digital sequence sampling.

2 TESTING PATH PLANNING OF COORDINATE MEASURING MACHINE

2.1 Problem Domain Analysis

In the coordinate measurement of parts, path planning is a complex combinatorial optimization problem. In the CAIP system of CMM, measurement path planning is a very important content. The main purpose of path planning is to generate a detection path with short moving distance and no collision with the workpiece or fixture according to the measurement requirements of the parts to be tested. Therefore, the quality of path planning will directly affect the detection efficiency of CMM. In order to enable the CMM to complete the testing task automatically, the testing sequence of each point to be measured on the part must be planned reasonably.

Before the measurement, according to the features of the parts to be tested, the placement posture of the parts on the CMM worktable should be considered, and the necessary fixtures should be correctly selected for the parts with special shape or size. When placing the parts, it is necessary to consider how to make the parts placed or clamped at one time so that the probe system can detect as many items to be measured as possible.

The minimum testing unit of CMM is a single testing surface, which requires that we must finish testing the measuring points on one measuring surface before we can carry out the measurement of the next measuring surface. Because in the measurement of parts, different probes and different probe directions are often needed according to the position and shape of the geometric features, so it is necessary to change the probe or change the angle of the probe in the process of measurement. It takes about 3-5 seconds to change the direction of the probe each time. If the probe is changed frequently, the efficiency of the measuring machine will be affected, and the most important thing is that it will bring about a loss of accuracy. Therefore, on the premise of ensuring the measurement accuracy, the replacement of the probe and the transformation of the probe angle should be reduced as much as possible.

If the workpiece needs to use several different probes in the measurement, the improper selection of the probe may lead to the change of the measurement error. Therefore, when selecting the probe, it is necessary to consider the type of geometric features on the workpiece and select the probe that is always used most in measurement. Based on the above analysis, in order to improve the measurement accuracy and detection efficiency of CMM, the following two points should be considered in path planning: 1) the transformation times of probe type and probe angle are the least in the detection process. 2) the path of probe movement should be the shortest.

2.2 Measurement Path Generation

The measuring path of the CMM can be manually controlled by the operator at any time, or the path can be set by the control software to run automatically. The measuring path of CMM mainly consists of three elements: the actual measuring point, the normal vector of the actual measuring point and the obstacle avoidance point. The measurement path for each test item is a collection of a series of measurement points and their normal vectors and obstacle avoidance points.

When the contact probe is used to detect the parts, it should be in accordance with the principle of normal contact measurement. The measurement path is generated according to the parameters such as the position of the measuring point, the normal direction of the measured surface at the measuring point, the related safe distance, the fallback distance and so on. The advantages of normal contact measurement are as follows: 1) the normal vector of the detection point is known, so it is easy to compensate the probe radius and reduce the error; 2) in normal contact measurement, the moving direction of the measuring rod is perpendicular to the normal direction of the surface to be touched, which reduces the possibility of slipping when the probe contacts the measured surface. The schematic diagram of normal contact measurement is shown in Figure 2.

When the CMM uses the contact probe to measure, the path recorded by the CMM is the trajectory of the ball center of the probe. When the normal vector direction of the surface of the measured point is the same as the contact direction of the probe, the position coordinate of the measuring point and the spherical center coordinate of the probe are different from the measuring ball radius r, so the position recorded by the measuring software is an envelope surface with a distance of r from the surface to be detected. If we want to get the coordinate value of the surface point of the part, we should make corresponding probe compensation for the measured data of the coordinate measuring machine.

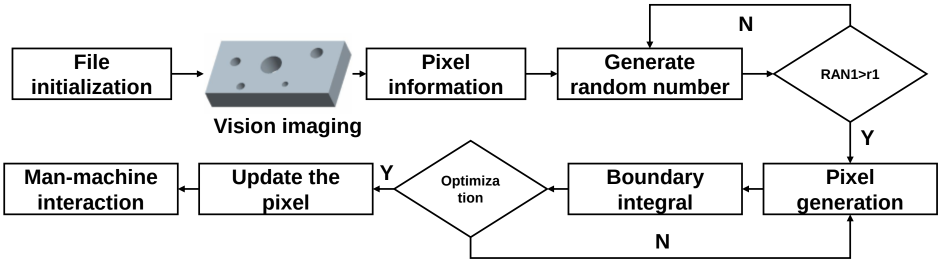

Figure 2: Normal contact measurement of probe.

2.3 Design Principles of Measurement Path

The design of the measurement path should mainly consider the following problems:

1) safety, when the probe moves from the current detection point to the next detection point or obstacle avoidance point, the probe will not collide with the workpiece;

2) the measurement path should be short and fast. Reduce the number of changes of the probe and its angle as much as possible to make the probe reach the next measuring point;

3) the trajectory of the probe is natural to avoid sharp turns in the path.

Figure 3 shows three different detection paths on the same circle. In the picture, Pi is the current measurement point, Pi+1 is the next point to be measured, and C1, C2, C3 and C4 is the barrier avoidance point. When there is only one obstacle avoidance point, the path of the probe running route pic1,C1Pi+1 is longer, and the obstacle avoidance point C1 is far away from the geometric features to be measured, so the probe is easy to collide with the workpiece or fixture when moving. When there are two obstacle avoidance points, the probe walking route is shorter than the former, and the walking route is natural, so it is not easy to collide with the workpiece or fixture. There are four obstacle avoidance points in the picture, and the walking path of the probe is shorter than the first two. However, the probe has to accelerate and decelerate before and after the operation of each obstacle avoidance point, and this frequent acceleration and deceleration will prolong the running time of the measuring machine probe. Therefore, from the comprehensive consideration of the probe walking path and running time, it is more appropriate to choose a specific path.

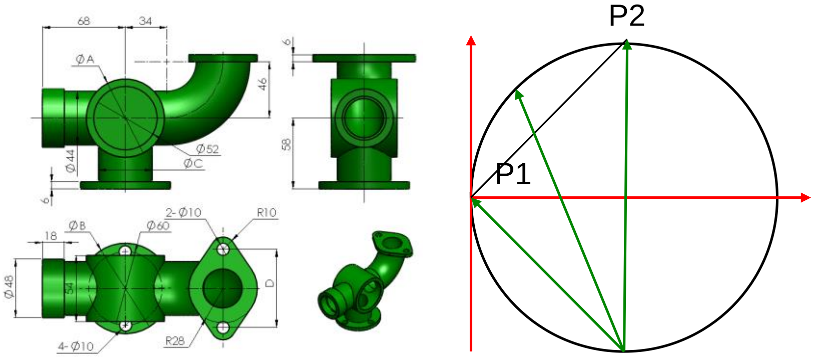

Figure 3: Comparison of different measuring paths.

In the actual measurement, when the measuring parts are relatively simple and there are few items to be tested, the advantage of path planning is not obvious. However, the measurement of complex parts may include dozens of features to be tested and hundreds of measurement points. The more measurement items, the larger the sorting scale, and it is difficult to get the optimal measurement path scheme by relying solely on manual experience. The research on the reasonable planning of measurement path is of great significance to improve the detection efficiency of products.

Measurement path planning is an important part of intelligent coordinate measuring machine inspection planning for complex parts, which is of great significance to improve the measurement efficiency and automation level of CMM. In the existing research on measurement path planning, related studies pay more attention to how to reduce the walking path of the probe, while other influencing factors, such as probe replacement and probe angle transformation times, need to be further studied. The frequent transformation of probe and probe angle is not only time-consuming, but also brings the loss of accuracy, especially for the parts with more measurement items and complex shape, different probes and multiple probe angles are needed. It can be seen that path planning is a complex combinatorial optimization problem. Therefore, how to plan the measurement path of complex parts in advance in order to shorten the probe moving distance, reduce the number of probe replacement and probe angle transformation, is the key problem of path planning.

2.4 Global Measurement Path and Local Path

Detection path planning is an important part of CIAP system, and its purpose is to obtain collision-free safe path with short measuring distance. In the contact inspection, the probe moves near the inspection item determined by the workpiece and touches the surface of the workpiece to measure, so the obstacle space of CMM includes not only the part itself but also the fixture used. Therefore, the optimal detection path is the one that sequentially connects the measurement points and avoids obstacles. Simply considering the shortest path will inevitably lead to frequent changes in the probe and probe angles, resulting in the shortest detection path may not be the optimal path. In the actual measurement, because the complex shape of the workpiece needs to take into account the different angles of the probe and the reachability of the probe, it is very difficult to find the optimal collision-free path by manual experience. In order to simplify the problem of path planning, path planning is usually divided into global path planning and local path planning.

Global path planning takes the collection of all the geometric features to be tested on the part as a whole, but does not consider the distribution of measuring points on the local surface for the time being. The main task is to determine the detection surface of each feature to be measured and the measurement sequence between the features. Local path planning is a sampling strategy determined according to the detection requirements to find the shortest measurement path through all the measurement points in each detection plane of the geometric features to be tested. The path connection between the detection surfaces is optimized by the principle of shortest path. At present, there are many researches on local path planning, and the mainstream measurement software has the automatic measurement function of plane, cylinder, circular hole, sphere, cone and other common features. This paper mainly introduces the global path planning problem.

The determination of the measurement order of geometric features to be tested depends on the technology and experience of the surveyors, and the priority of measurement is usually determined according to the category and grade of tolerances, or according to the sampling strategy determined in the previous period, the measurement is carried out in the order that the number of measuring points on each testing surface is from more to less; in addition, the measurement can also be classified according to the type of geometric features to be tested on the parts. In the above methods, although the detection purpose can be achieved in the end, the probe increases the length of the measurement path and the transformation times of the probe angle in the process of moving, which affects the measurement efficiency. The measurement of parts needs to select the probe specification and probe angle according to the touchability of the testing feature and the testing surface. At the same time, the geometric features to be tested are usually attached to a geometric surface, and the attached surface of the features to be tested has become an important factor affecting the grouping and ranking of features to be tested in path planning. Therefore, the global path planning needs to consider how to detect as many geometric features as possible under the same probe angle when the parts are clamped at one time.

3 3D-CAD INTELLIGENT PLANNING PATH

3.1 Establishment of a Simplified Model for Three-Coordinate Measurement

After completing the global path planning and local path planning of the geometric features of the whole part to be detected, it is necessary to check the collision of the generated complete detection path. In the mechanism module of Pro/Engineer, a simplified model of CMM and probe can be assembled by adding various constraints. In the simplified model, the motion of the probe can be decomposed into three translational motions in X, Y and Z directions. According to the rotation characteristics of the probe, a simplified model of the probe is established, so that the probe can rotate around the A axis and B axis, and the position of the probe angle can be determined. The simplified model of the probe is shown in Figure 4.

For the established simplified model, the collision check of the measurement path is carried out by using the animation simulation module of Pro/Engineer. According to the position and distribution of the points to be measured, the motion position of the measuring ball of the probe is determined, and the trajectory of the probe is guided according to the detection path that has been planned in the previous period. In the animation simulation, Pro/Engineer has its own collision detection module, and its main functions include: 1) it can select three modes: global collision detection, partial collision detection and no collision detection. 2) in the collision detection, when the probe collides with the workpiece, the fixture or the CMM itself, the probe of the CMM will stop at the position of the part model where the interference occurs, and the collision part will show bright red and sound alarm will be issued to remind the user of the collision. Here you can see the collision and interference between the probe and the cylinder on the part.

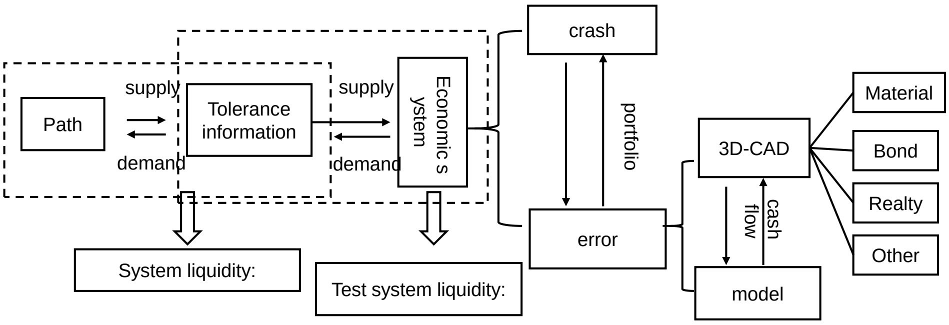

Figure 4: Simplified model of probe.

3.2 Collision Avoidance

Collision avoidance is often combined with collision checking. When the probe collides, the measurement path is adjusted by determining the obstacle avoidance point, that is, under the premise that the movement of the probe does not collide with other workpieces or fixtures, the optimal path to the end point is obtained. Usually, different obstacle avoidance strategies are adopted according to the position where the probe collides. When the pedestal collides with the part model, the main obstacle avoidance strategy is to increase the rotation length of the probe; when the measuring rod collides with the part model, the main strategy is to change the probe orientation; when the needle ball and the part model are mainly inserted into the empty walk point to detour. At present, there are not many methods for inserting the location and number of avoidance points. However, the main obstacle avoidance strategies for external circular parts are the relatively mature outer circular obstacle avoidance method, and the edge line obstacle avoidance method is used for simple prism parts.

The geometric features of outer circle mainly refer to (elliptical) cylinder, cone, sphere and so on. When the outer circle feature of the probe moves in a straight line, it is necessary to avoid obstacles if the probe collides with it. The outer circle feature mainly adopts the method of avoiding obstacles in the outer circle to automatically generate the avoidance points. The outer circle obstacle avoidance method is to set a uniform number of fixed points between the two measuring points of the outer circle feature. When the density of the measuring points on the outer circle features is not too sparse (more than four points are evenly distributed around), it is usually necessary to set up only one obstacle avoidance point between the two measuring points. For a cylindrical workpiece, the angle between An and B is 90 degrees. If it runs in a straight track, the probe will collide with the workpiece. After adding the barrier point P, after the probe wants to go according to the straight path of A-P-B, the collision can be avoided.

4 CASE ANALYSIS

4.1 Sequence Analysis of Global Path Planning for Complex Parts

For a complex 3D CAD part model, the items to be tested can be determined according to the tolerance information marked on the model. In addition to the plane features, the geometric features to be tested are mainly attached to the upper surface, step surface and front-end surface, and the geometric features to be tested are mainly round holes, cylinders, cones, keyways, balls and so on.

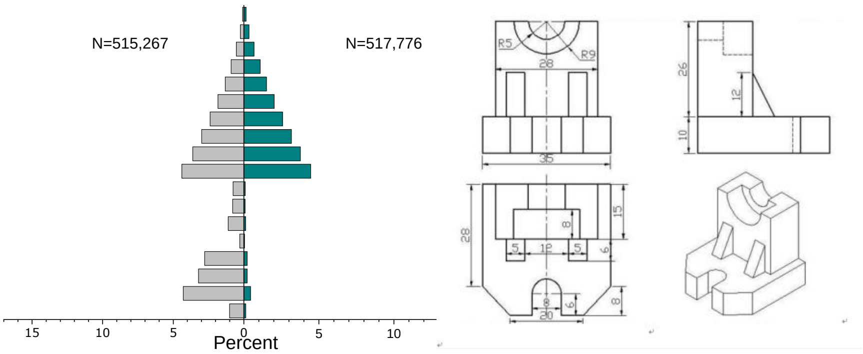

Figure 5: Measurement information of parts to be tested.

The geometric features of the part to be tested are mainly attached to the upper surface, the step surface and the front-end face. In the measurement, it is necessary to consider how to detect as many geometric features as possible when the parts are clamped at one time. Therefore, after the above analysis, in order to improve the accuracy of parts testing and reduce the number of clamping times, the following surface should be used as the reference plane and placed on the testing table of the coordinate measuring machine (CMM). However, as can be seen from Figure 5, the overall size of the part is 400x230x30mm. Considering that the parts are relatively thin, if the probe is placed directly on the worktable of the CMM, when the probe measures the hole features on the front surface, because the probe itself has a certain size, the probe will collide with the worktable and affect the measurement. Therefore, it is necessary to select the standard backing plate of the special fixture or measuring machine to be put on the worktable, and then put the parts to be tested on the fixture or backing plate, so that all the geometric features to be tested can be measured at one time.

4.2 Selection of Touch Angle

Before the inspection of related parts, the first step is to establish a suitable probe system according to the characteristics of the parts, including the selection of measuring seat, measuring rod, measuring needle and so on. The system realizes the dynamic visual configuration of the probe system through the dialog box. The middle view window displays the currently configured probe components in real time, and the left side is the corresponding component list. On the right side is the name of each component and its related parameters that can be assembled with the current probe component library filtered from the probe component library. The component assembly of the probe system can be easily visually modified through the add and delete buttons next to it.

Figure 6 shows the relationship between the measuring position and azimuth. The user can easily adjust the angle size to set the stylus in different directions and mark them with different labels. The azimuth change caused by the whole angle setting process will be displayed in real time in the window of the upper left corner so that the user can judge intuitively. The defined azimuth stylus and related parameters are displayed in the list below, where the user can select the desired stylus and calibrate the stylus automatically. After setting up the probe system and defining the probe, the system can select the probe with the appropriate angle to measure. However, the needle needs to be calibrated before it is measured, and the reference ball is used to calibrate the needle. There are two ways to obtain the reference sphere information: typing and calibration, but the reference sphere diameter must be input.

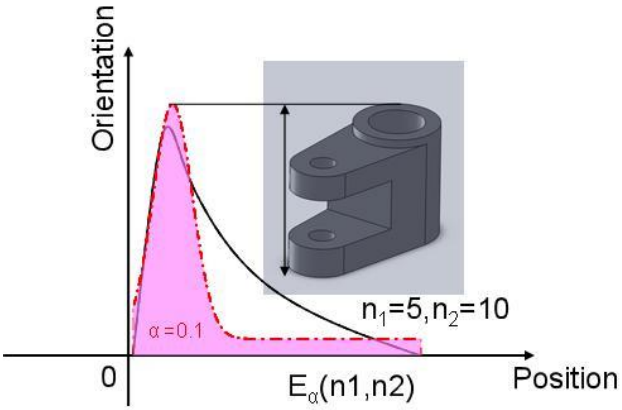

Figure 6: The improvement of picture quality brought about by 3D technology.

If the spherical center coordinates of the reference sphere are known, the nominal information can be input manually, otherwise the actual measurement and calibration must be carried out, and the measured spherical center coordinates will be used as the nominal spherical center. The system obtains the feature information related to detection from the model through the service, and on this basis, uses the planning service to automatically plan the distribution of sampling points of the corresponding feature measurement and the collision-free detection path. The measurement points are evenly distributed on the surface and avoid discontinuous areas. The generated detection path sequentially connects the measurement points and can avoid possible collisions. The interface can directly display the results of the planning, and can simulate the measurement process off-line and display the actual measurement process on-line in real time. In addition, a row of buttons is designed at the top of the dialog box to realize real-time interactive sampling and editing service.

4.3 Measurement Information of Parts

The so-called measurement information of the parts, that is, the geometric information and tolerance information of the parts related to the measurement, is shown in Figure 7. Geometric information refers to the voxel type, positive and negative attributes, shape size, base point coordinates (refers to the coordinates of the geometric center of the feature) and the direction vector of the feature placement mode, while the tolerance information is divided into dimensional tolerance, shape tolerance and position tolerance. The shape and position tolerances include 14 kinds of tolerances, such as straightness, flatness, roundness, parallelism, verticality and inclination. The research on the key technology of generating and obtaining part measurement information is to study the generation and acquisition mechanism of measurement information of different kinds of geometric bodies (especially complex parts) on the basis of given testing items and contents. A complete part measurement information model is formed, which lays the groundwork for the follow-up work of part measurement path planning, collision inspection, pose recognition and measurement program generation. This research is one of the key contents of intelligent coordinate measuring machine (CMM). In order to represent the three-dimensional shape completely, we need both geometric information and topological information. Topological information refers to the number and types of topological elements (vertices, edges and surfaces) of an object and the relationship between them.

In order to make the established three-dimensional model can be used for measurement, it is also necessary to mark the tolerance information on the three-dimensional shape, which provides the data basis for the identification and extraction of subsequent inspection information. In the interior of the computer, the part model is not stored in the system database as a whole, but is represented by the basic voxels and their set operations (such as union, intersection, difference), that is, the binary tree structure is generated by the Boolean model, and the storage is mainly the generation process of the object. This method is called CSG method (Constructive Solid Geometry, construction solid geometry method. After obtaining the measurement information of the parts, we first need to determine the main inspection surface and the auxiliary inspection surface according to the inspection tasks, requirements and the measurement information that has been obtained, and then determine the placement mode of the workpiece on the worktable.

There are usually two ways to place the parts: one is to place the parts through the measuring fixture, which is suitable for mass inspection and production; the other is to place the parts at random on the work plane of the coordinate measuring machine through observation. This placement method is suitable for the detection of a single part. The principle of placement is to facilitate the measurement of various features in order to reduce the number of probe changes or changes in the measuring direction. After the problem of workpiece placement is solved, the corresponding part coordinate system must be established. The establishment of the part coordinate system is very flexible. In the process of measurement, we can establish and call the part coordinate system many times according to the specific situation and the need of measurement.

5 CONCLUSION

This paper aims at the development of intelligent CMM inspection planning system based on 3D, from the overall analysis and design of the system to the extraction of detection geometric information, sampling planning, detection path planning and automatic generation of quack measurement program and other related key technologies will be studied.

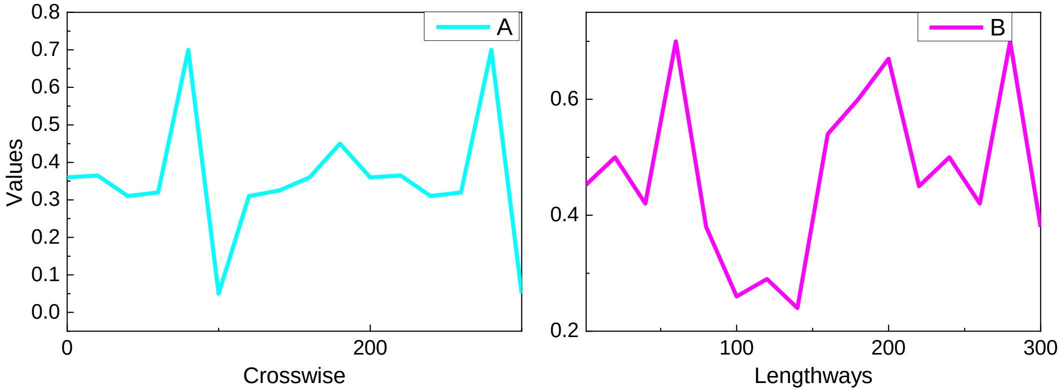

Figure 7: 3D technology to capture the expression and motion of a character.

This paper briefly analyzes the relevant factors that determine the number of sampling points and summarizes the point requirements for the distribution of sampling points, and in view of the shortcomings and limitations of various methods of sampling point distribution on the general surface, a sampling strategy with adaptive step size is proposed, which solves the problem of sampling planning on the general surface. In the specific implementation of sampling planning, it is divided into two ways: edge-based and face-based geometric element measurement and sampling. Considering the requirements of distribution points, specific sampling algorithms are designed respectively, focusing on the analysis of the differences between edges and faces. The experimental results of sampling planning show that the step size adaptive resampling method based on regular uniform distribution is not limited by whether the surface is continuous or not, and can well adapt to the surface shape features, while uniformly distributing the sampling points as far as possible. Avoid the discontinuous area on the surface, which has a good adaptability to the surface of all kinds of complex conditions. It makes up for the lack of homogenization of random sampling and the requirement of complete and continuous surface based on digital sequence sampling.

Jin Guang, http://orcid.org/0000-0002-0322-9922
Fan Li, http://orcid.org/0000-0003-2580-7639

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