CAD Reverse Modeling Based on Multi-sensor Measurement

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Abstract. Coordinate measuring machines are standard three-dimensional precision measuring equipment in the manufacturing industry. They are widely used in aerospace, automotive, shipbuilding, equipment manufacturing, and mold manufacturing. This paper addresses the application problems in the field of mechanical engineering from the perspective of information science. The process of three-dimensional information acquisition by a coordinate measuring machine is described as a hierarchical, closed-loop structure based on multi-sensor fusion. The introduction of computer vision makes the measurement flexible and intelligent, which increases the measurement speed and avoids the dispersion of measurement results caused by manual intervention. Based on the composition of flexible coordinate measurement system and the support of multi-sensor fusion, this paper studies the multi-sensor physical integration, model information acquisition and model coordinate fitting. This paper focuses on the modeling flaws in the reverse modeling method based on surface reconstruction, and analyzes the reverse modeling method based on solid reconstruction in the reverse modeling method. Parameterized editing and modification of the extracted solid features can accurately define the geometric parameters of the features and the constraint relationship between the features. In this paper, using the feature recognition and extraction function in solid reverse modeling method, a reverse modeling method for incomplete data is proposed, and the modeling process and characteristics of the method are specifically introduced and verified.

Keywords: Multi-sensor Measurement; Reverse Modeling; CAD
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1 INTRODUCTION

The great significance of reverse engineering is that it not only simply restores the original object, but also carries out a secondary innovation based on the restoration [1]. With the rapid development of computer, numerical control and measurement technology, reverse engineering technology has been widely used in many fields [2]. When designing a workpiece model that can be finalized through experimental testing, the reverse engineering method is usually used, such as

aerospace, automotive, and other fields [3]. First, various performance tests on the model are required to establish a product model that meets the requirements. Reverse engineering converts the product into a 3D CAD model.

At present, there are more and more researches on multi-sensor integration, but the research on multi-sensor combination focuses on simple probe replacement [4]. There is no good selective planning and measurement of a variety of measurement equipment, which makes the measured data quality and efficiency. The integrated research and charging of multiple surface digital methods has become an innovative idea that attracts much attention. After consulting many research materials, it is found that the integrated measurement methods are mainly divided into passive measurement methods and active measurement measurement methods, the integration of CMM and visual measurement methods, and the integration of passive measurement methods. In the realization of measurement, there is complementarity between active vision measurement and passive vision measurement, so it has become the focus of research by many researchers. For example, Buonamici et al [5] have integrated the occlusion contour restoration shape method with the line structured light method. Ingrassia et al [6] have combined the stereoscopic vision and the projection grating method of spatial coding technology into a curved surface measurement system, which has greatly improved the measurement range and solved the problem of insufficient contour recognition in laser scanning. In the passive visual measurement method, due to the increasing requirements for measurement under many conditions, the use of single visual measurement information has been unable to meet the measurement of complex surfaces. Cho et al [7] have combined brightness, color, contour, brightness, and other factors to study the synthesis. The integration of stereo vision and light and dark information measurement methods solves the problem of difficult points when measuring complex parts in stereo vision. Kirkwood et al [8] have proposed the method of reconstructing the three-dimensional shape of an object by using the brightness information of the contour information to reconstruct a highly accurate model. Carfagni et al [9] first use vision systems or laser scanning to build an initial three-dimensional model to reduce the path planning time of CMM in reverse engineering, or to study directly locating parts on CMM for digitization. But this measurement method is very time consuming, especially for the measurement of complex parts or freeform surfaces. How to improve the automation degree of the multi-sensor combination measurement system and how to optimize the CMM measurement path to construct a CAD model that meets the accuracy requirements still need to be studied. Vilmart et al [10] have studied the geometric reference volume error problem in the measurement process of the combined system, and through the error compensation of the measurement data, the accuracy of the aligned data is finally improved. In this case, the accuracy of the measurement geometry directly affects the level of the final data, reducing the flexibility and reliability of the alignment. In addition, there are relatively many researches on the alignment algorithms of dense data, and the precise alignment algorithms between dense data points and sparse data points are relatively limited.

This paper proposes a novel automatic measuring method for a coordinate measuring machine. A small industrial camera is fixed on the measuring base of a coordinate measuring machine to realize automatic measurement under the guidance of computer vision. The process of three-dimensional information acquisition by a coordinate measuring machine is described as a hierarchical, closed-loop structure based on multi-sensor fusion. The introduction of computer vision achieves the flexibility and intelligence of coordinate measurement, improves the measurement speed of the coordinate measurement machine, and reduces the manual workload. The most widely used modeling methods based on curve and surface features in traditional reverse modeling methods are analyzed and summarized. Aiming at the shortcomings of modeling methods based on curve and surface features, a reverse modeling method based on solid model recognition and extraction of solid model reconstruction was proposed. A hybrid inverse modeling method based on surface and solid features was proposed to reconstruct a solid physical model of a product that cannot be reconstructed using a single inverse modeling method for CAD model reconstruction.

2 COORDINATE MEASURING SYSTEM BASED ON MULTI-SENSOR MEASUREMENT

2.1 Multi-sensor Integration

The probe of a CMM can be regarded as a sensor, which is divided into a contact probe and a non-contact probe. At present, the commonly used three coordinate measuring machines on the market usually have only one type of probe installed. When measuring, they can only measure in one way. When this measurement method cannot meet the measurement requirements of the workpiece or the measurement result is not satisfactory, the original probe must be removed and another probe must be installed. Such a process makes the measurement efficiency very low, and requires a lot of manual intervention.

The multi-sensor integrated measurement system consists of high-precision coordinate measuring machines, contact probes, vision systems, laser non-contact probes and computers and other electronic equipment. The multi-sensor integration method is used to collect the data of the workpiece, so as to further position and coordinate the workpiece. The advantages of each sensor can be used to improve the intelligent detection of the coordinate measuring system and reduce manual intervention as much as possible. In the system constructed in this paper, we integrate a vision sensor camera, a line-scan laser triangulation sensor, and a contact sensor provided by itself. Multi-sensor integrated micro measurement system is shown in Figure 1.
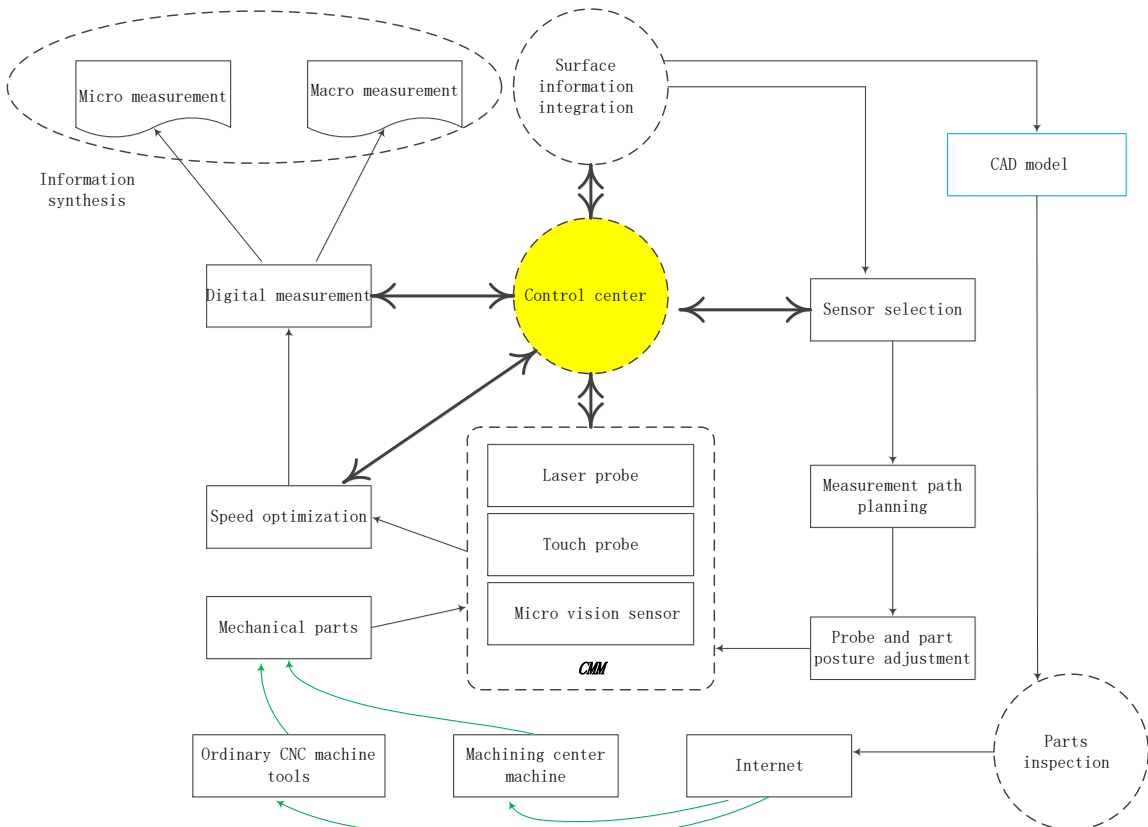

Figure 1: Multi-sensor integrated micro measurement system.

2.2 Using Machine Vision to Obtain Three-dimensional Information

Traditionally, when a three-dimensional measuring machine is used to detect a workpiece, a three-dimensional coordinate of a partial point of the measured workpiece is usually obtained manually using a touch probe, and a machine coordinate system of the workpiece in the three-dimensional measuring machine is established, and the machine coordinate system of the workpiece is fitted to the CAD coordinate system, so that the coordinates of the workpiece are used to guide the high-precision measurement of the measuring machine. In actual work, the work of fitting the two coordinate systems is very unintelligent, and it needs to be done manually. The experience of the inspectors and errors in the inspection process will greatly affect the results of the inspection.

On the other hand, due to the characteristics of contact measurement, the probe needs to be lifted point by point during measurement. This results in a slow measurement speed and low efficiency, but its measurement accuracy is the highest compared to other measurement methods. Therefore, it is necessary to use it to make high-precision measurements, but it is obviously a little "big material and small use" for just positioning the parts and fitting the coordinates.

By using machine vision to obtain three-dimensional information, fast and intelligent measurement results can be obtained. This is because compared with contact measurement, the machine vision method can make low-precision and fast measurement of the measurement object. For parts with high accuracy requirements, in order to speed up the measurement and modeling time, firstly you use the machine vision system to quickly obtain the geometric features of the surface. Through the multi-sensor measurement information intelligent fusion and other technologies, the touch sensor is measured and guided to achieve fast and high-precision intelligent measurement. Multi-agent-based part process information model is shown in Figure 2.
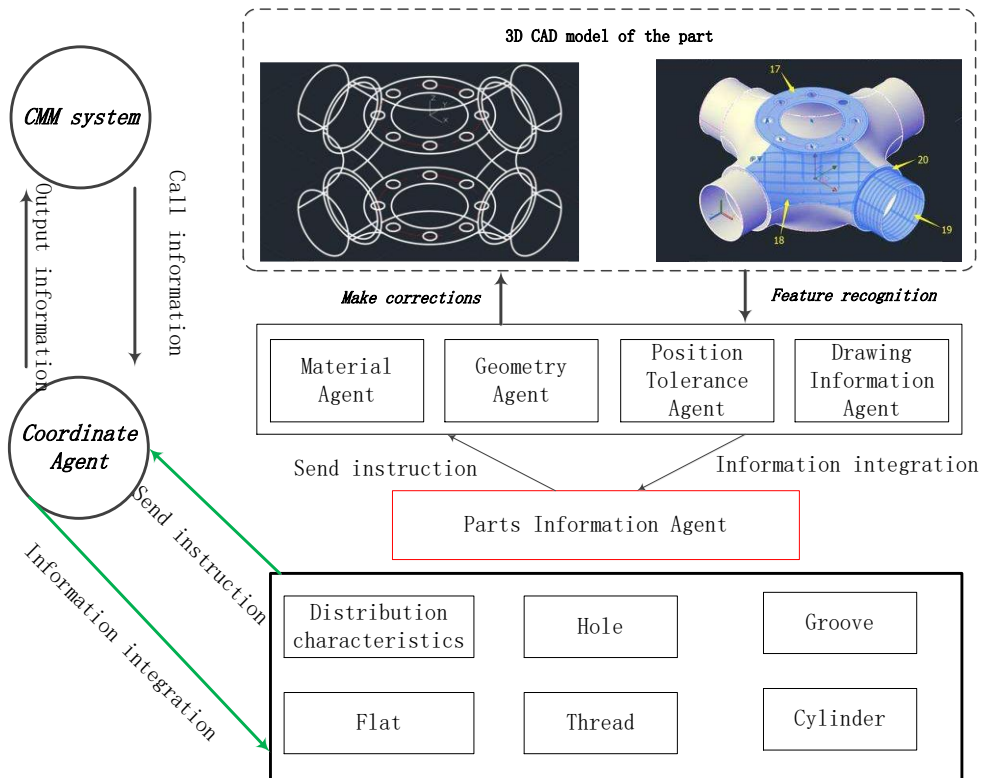

Figure 2: Multiagent-based part process information model.

2.3 Coordinate System Alignment Technology

Integrating multiple sensors into an integrated multi-sensor measurement system is the basis for multi-sensor measurement. Accurate alignment of multi-sensor measurement data is an important part of subsequent reverse modeling. The unification of coordinate system is an important step in the planning of complex feature paths. In the measurement of complex parts, since one measurement device cannot complete the measurement at one time, the data after the two measurement devices are combined. At this time, the uniformity of the data coordinate system needs to be considered. The establishment of the coordinate system is directly related to the accuracy and completeness of the overall data during the process of assembling the data. If different internal coordinate systems are used to locate different point cloud data during the measurement, the point cloud data will not be processed and shaped during processing. The coordinate normalization data processing directly assembles them based on points, which will cause multiple pieces of measurement data errors. The larger the number of assembles, the greater the overall model error.

When measuring a complex and large three-dimensional workpiece, the same sensor is usually required to measure data from different perspectives, and multi-sensor is used to measure different angles and mixed measurements. The same sensor measurement and multi-sensor measurement data are located in the coordinate system defined by themselves. In order to establish a unified and complete measurement data, it is often necessary to align the data measured by multi-vision or multi-sensors to the same coordinate system.

Alignment technology is a key factor that affects the quality of the final model during reverse modeling. If different measuring equipments are used to measure the same object, combining the two parts of the measurement data often requires establishing a common coordinate system to merge the two data into a complete physical model. The most commonly used method of establishing the workpiece coordinate system is the 3-2-1 method or using three or more standard balls to establish a spatial coordinate system before measurement.

After the two-part model is aligned by the common coordinate system, it is not a whole. At this time, you need to use the "Intersect" tool to combine the two parts into a whole or Boolean operation to shear or add.

Combining the advantages of two different measurement methods and the reverse reconstruction model using hybrid modeling technology, it fully demonstrates the advantages of integrated measurement of two types of equipment in collecting data and the characteristics of rapid and correct modeling. The quality of the CAD model and the flexibility of operation are improved through integrated measurement. This has certain reference role in reverse modeling.

2.4 CAD Model Interface

When using a coordinate measuring machine for a measurement task, the first step in the measurement process is to define the measurement task, that is, to define the detection elements and obtain the tolerance requirements related to them. When defining the testing elements, the commonly used method is to manually input the required testing information, such as tolerances, based on the engineering drawings in the measurement software dialog box. This will not only cause unnecessary repetitive labor, but also easily lead to errors. Therefore, according to the design data file of the part, the detection features are automatically extracted from the model, and the three-dimensional coordinate measuring machine can be automatically recognized, then the above problems are solved. CAD unified interface model structure is shown in Figure 3.

In order to realize the automation and intelligence of the measuring machine system, the integration of CAD must be realized first, which needs to build a bridge between them, so that the coordinate measuring machine can read out the items to be tested and the tolerance requirements.
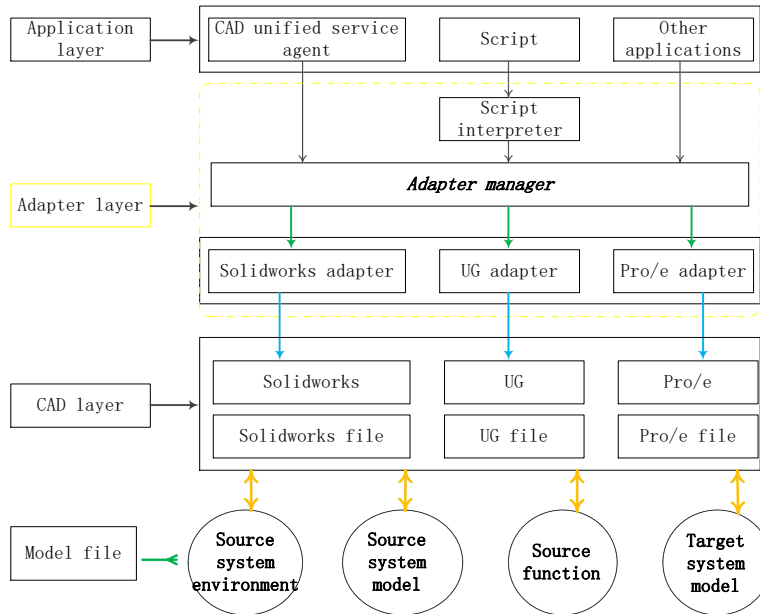
Figure 3: CAD unified interface model structure.

2.5 Surface Recognition and Fitting

The main function of this part of work is to determine the geometric shape of the part, so as to determine the placement method, placement position, and placement direction on the workbench, and finally establish the mathematical relationship between the part coordinate system and the model coordinate system. In the current measurement machine, the part coordinate system is generally established by manually measuring several points, which is inconsistent with the purpose and task of the intelligent CMM system. If the automatic recognition function of the part pose and the automatic establishment of the part coordinate system cannot be achieved, the intelligent detection of the CMM cannot be realized. Therefore, the problem of surface identification and automatic fitting of the coordinate system is also a key issue for flexible coordinate measurement systems. In this paper, a new method for fitting CAD coordinates and CMM coordinates using part feature edges is proposed. The accuracy of fitting the CAD coordinates and CMM coordinates is shown in Figure 4.
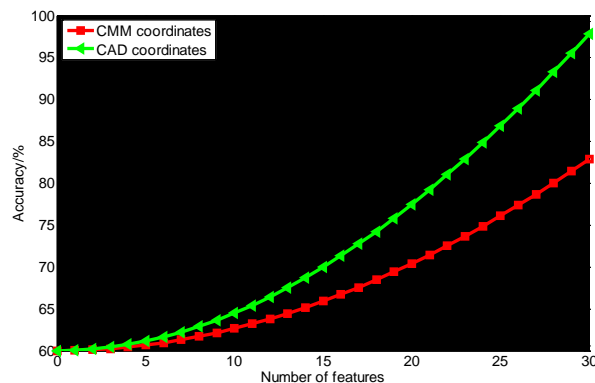

Figure 4: CAD coordinate and CMM coordinate fitting accuracy.

3   HYBRID INVERSE MODELING BASED ON SURFACE AND SOLID FEATURES

Reconstruction of the inverse modeling method based on the characteristics of curves and surfaces yields a surface model, which can automatically fit complex free-form surfaces with high accuracy. However, when fitting and extracting a regular surface, it is impossible to extract the parameters of the characteristic surface (such as the radius value of a cylindrical surface) and the exact constraint relationship between the surfaces. Furthermore, the reconstructed surface model cannot be directly used for redesign. The solid surface model needs to be imported into the forward modeling software and the surface is cut and stitched to construct a solid model, and then the solid model is edited and modified. However, the process of importing the reconstructed surface model into the forward modeling software through parameter conversion is cumbersome and the steps of man-machine operation are complicated, which greatly increases the modeling time. The inverse modeling method based on solid feature recognition and extraction can identify and extract solid features from the mesh surface model, and can directly modify the solid features to realize the redesign based on the reconstructed CAD model. However, the result of this method for identifying and extracting complex free-form surface features is not ideal. Therefore, the accuracy of the modeling results is relatively low when the method is used to reconstruct a CAD model of a product with complex curved surfaces in the geometric features. For example, when extracting complex free-form surfaces, the error between the extracted surface results and the mesh surface model is large, as shown in Figure 5.
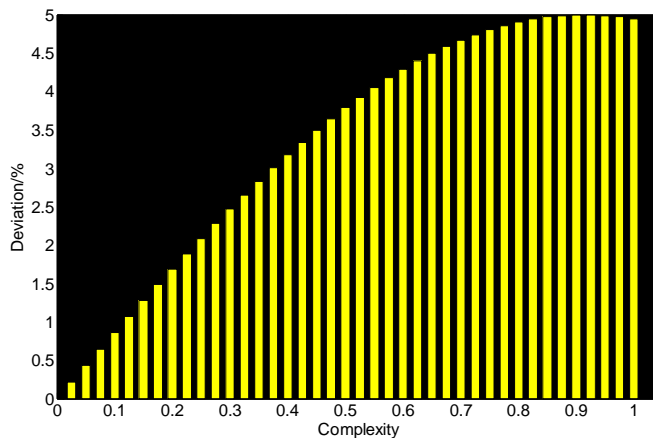

Figure 5: Extracting the deviation of complex free-form surfaces.

3.1   Hybrid Modeling Method Based on Surface and Solid Features

With the development of modern manufacturing industry, the appearance characteristics of industrial products and components are no longer composed only of regular curved surfaces such as planes, quadric surfaces, or only complex free curved surfaces. Therefore, if you want to perform reverse modeling and reconstruction on product or component models with more and more diverse appearances, in the current situation where the modeling capabilities of various types of modeling methods are limited, you need to combine the advantages of different modeling methods to achieve reconstruction of complex models.

The hybrid inverse modeling method based on surface and solid features proposed in this paper combines the complex free-form surface fitting function in the inverse modeling method based on curve and surface features and the regular geometric features in the inverse modeling method based on solid feature recognition and extraction. Recognition, extraction and redesign functions can effectively and quickly reconstruct a solid physical model of a product with complex and diverse appearance features. This method first preprocesses the original set data and obtains the mesh surface model, and then performs optimization processing such as denoising,

streamlining, and smoothing on the mesh surface model, so as to be able to fit a complex free-form surface with high accuracy. Then you apply the inverse modeling method based on solid feature recognition and extraction to extract meta solid features from the processed mesh surface model.

When applying computer-aided detection technology to evaluate the accuracy of the reconstructed model, it is generally compared with the original CAD data of the real object, and it can quickly know that there is a large error failure area in the reconstructed model. Since the original CAD data of the impeller case used is not available, the accuracy analysis is based on the smoothing of the collected original mesh surface model as the reference object, and the reconstructed solid model is used as the test object for error analysis. The results of the analysis are shown in Figure 6.
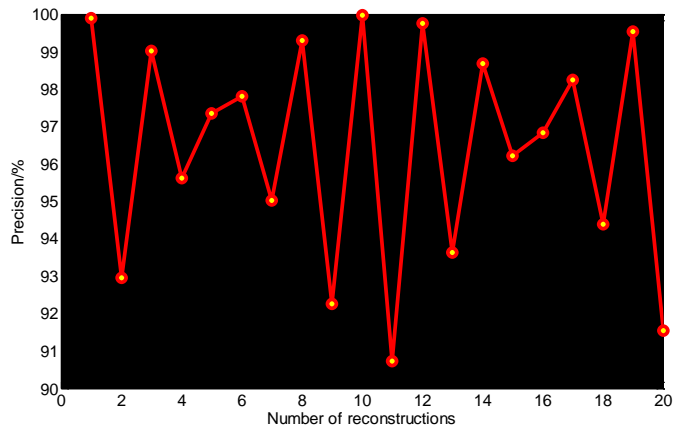

Figure 6: Precision analysis of solid model.

3.2 Model Reconstruction Based on Curve and Surface Features

The traditional reverse modeling technology is to reconstruct a complete, smooth and continuous surface model based on discrete data points. Therefore, the surface reconstruction method has become a key method in reverse modeling technology. According to the classification of the geometric characteristics of the product's appearance structure, the appearance features can generally be divided into regular feature surfaces and freeform surfaces. For regular characteristic surfaces, you can use planes, quadrics, and extruded surfaces to perform fitting reconstruction. For the free-form surface, under the constraint of continuity, the parametric surface can be reconstructed to be closed, directed, and the surfaces can be connected strictly according to the topological relationship.

Reverse modeling to reconstruct a surface model usually requires three stages (some of the original measurement data is in the form of a triangular mesh surface and does not need to go through the point cloud stage): the point stage, the polygon stage, and the surface stage. The processing of the point phase is mainly to align, filter, and sample the scattered point clouds to obtain an orderly and easy-to-handle point cloud. The processing at the polygon stage is mainly to reduce noise, hole repair and smoothing on the triangular mesh surface obtained from the point cloud triangulation to obtain a complete and smooth triangular mesh surface. There are two processing modes in the surface stage, namely precise surface reconstruction and parametric surface reconstruction. Accurate surface reconstruction is suitable for models of handicrafts with complex free surface features, and parametric surface reconstruction is suitable for mechanical product models with regular surface features. Figure 7 is a flow chart of reverse engineering.
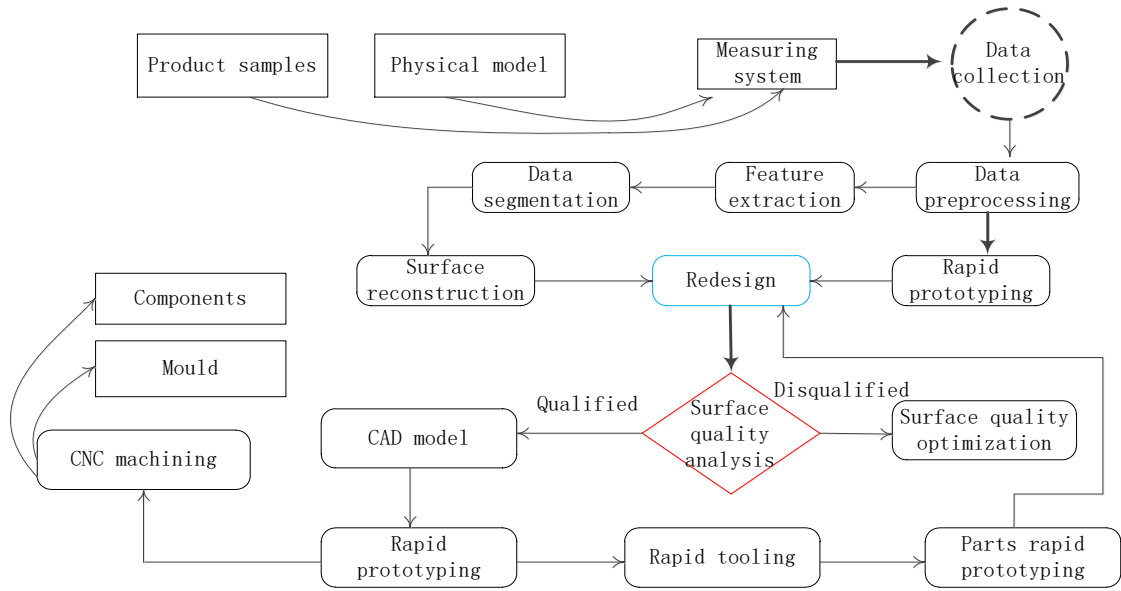
Figure 7: Reverse engineering flowchart.

The surface model reconstructed in the parameter stage is fitted and assembled according to the geometric characteristics of the surface, which can reflect the original design intent to a certain extent. In addition, after fitting the surface and the connection between the surfaces, the fitted surface model can be output to the mainstream forward CAD software through the parameter conversion function of the software for redesign or innovation based on reverse modeling. The result of the combined surface is not very accurate. Moreover, the process of parameter conversion and redesign is tedious, and the steps of human-computer operation are complicated. Error analysis is generally performed after surface reconstruction in forward software. The mold takes a long time. The relationship between the difference between the surface reconstruction and the modeling time is shown in Figure 8.
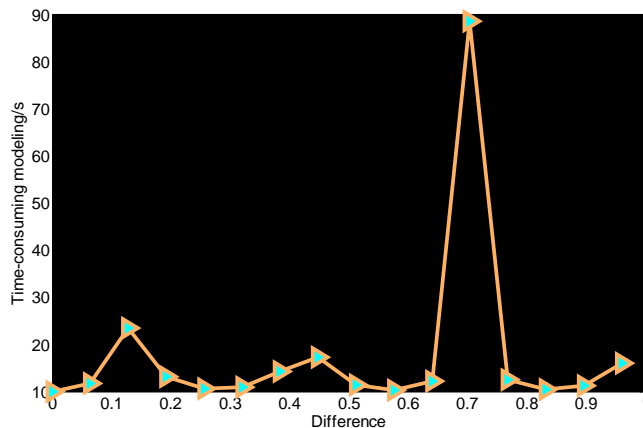

Figure 8: Relationship between the difference between surface reconstruction and modeling time.

4   CONCLUSION

Realizing the flexible measurement of CMM is the development direction of the new generation of CMM. It can realize the automation of the measurement process and the intelligentization of measurement decision. This will bring a new and broad use space to the three-dimensional coordinate measuring machine. In this paper, the composition of the flexible coordinate measuring system with multi-sensor integration is the main line, and the components of the flexible coordinate measuring system with multi-sensor integration are introduced. A vision sensor-based camera and a line-scan laser triangulation sensor are installed next to the measuring head of the coordinate measuring machine, and together with the contact probe of the original coordinate measuring machine, a multi-sensor integrated system is formed. The overall accuracy after installation on a CMM was verified. This paper studies the most widely used reverse modeling method based on surface model reconstruction and the reverse modeling method based on solid model reconstruction. A reconstruction method of solid model based on solid feature recognition and extraction was proposed. The principle and modeling process of the method are introduced in detail by reconstructing its complete solid model. The reconstructed solid model was edited and modified, and it was verified that the reconstructed solid model could be directly used for redesign.

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