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A Novel Modular Fixture Design and Assembly System Based on VR

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Abstract - **Modular fixtures are one of the important aspects of manufacturing. This paper presents a desktop VR system for modular fixture design. The virtual environment is designed and the design procedure is proposed. It assists the designer to make the feasible design decisions effectively and efficiently. A hierarchical data model is proposed to represent the modular fixture assembly. Based on this structure, the user can manipulate the virtual models precisely in VE during the design and assembly processes. Moreover, the machining simulation for manufacturing interaction checking is discussed and implemented. Finally, the case study has demonstrated the functionality of the proposed system. Compared with the immersive VR system, the proposed system has offered an affordable and portable solution for modular fixtures design.**

Index Terms* - *Modular fixture, desktop VR, assembly design, machining simlulation.

I. INTRODUCTION

Modular fixtures are one of the important aspects of manufacturing. Proper fixture design is crucial to product quality in terms of precision, accuracy, and finish of the machined part. Modular fixture is a system of interchange-eable and highly standardized components designed to securely and accurately position, hold, and support the workpiece throughout the machining process [1]. Tradition-ally, fixture designers rely on experience or use trial-and-error methods to determine an appropriate fixturing scheme. With the advent of computer technology, computer aided design has been prevalent in the area of modular fixture design.

In general, the associated fixture design activities, namely setup planning, fixture element design, and fixture layout design are often dealt with at the downstream end of the machine tool development life-cycle. These practices do not lend themselves well to the bridging of design and manufacturing activities. For example, very few systems have incorporated the functionality of detecting machining interference. This leads to a gap between the fixture design and manufacturing operations where the aspect of cutter paths is not considered during the design stage [2]. As a result, re-design can not be avoided when the cutter is found to interfere with the fixture components in the manufactu- ring set-up. Therefore, in order to bring machining fixture design into the arena of flexible manufacturing, a more systematic and natural design environment is required.

As a synthetic, 3D, interactive environment typically generated by a computer, VR has been recognized as a very powerful human–computer interface for decades [4]. VR holds great potential in manufacturing applications to solve problems before being employed in practical manufacturing thereby preventing costly mistakes. The advances in VR technology in the last decade have provided the impetus for applying VR to different engineering applications such as product design [5], assembly [6], machining simulation [7], and training [8]. The goal of this paper is to develop a VR-based modular fixtures design system (VMJFDS). This is the first step to develop an integrated and immersive environment for modular fixture design. This application has the advantages of making the fixture design in a natural and instructive manner, providing better match to the working conditions, reducing lead-time, and generally providing a significant enhancement of fixture productivity and economy.

II. OVERVIEW OF THE PROPOSED SYSTEM

The system architecture of the proposed desktop VR system is modularised based on the functional requirements of the system, which is shown in Fig.1. At the system level, three modules of proposed system, namely, Graphic interface (GUI), Virtual environment (VE) and Database modules are designed. For each of the modules, a set of objects has been identified to realize its functional requirements. The detailed object design and implementation are omitted from this paper. Instead, the brief description of these three modules is given below.

1) Graphic Interface (GUI): The GUI is basically a friendly graphic interface that is used to integrate the virtual environment and modular fixture design actions.

2) Virtual environment (VE): The VE provides the users with a 3D display for navigating and manipulating the models of modular fixture system and its components in the virtual environment. As shown in Fig. 1, the virtual environment module comprises two parts, namely assembly design environment and machining simulation environment. The user selects appropriate elements and puts down these elements on the desk in the assembly design area. Then he assembles the selected elements one by one to build up the final fixture system with the guidance of the system.

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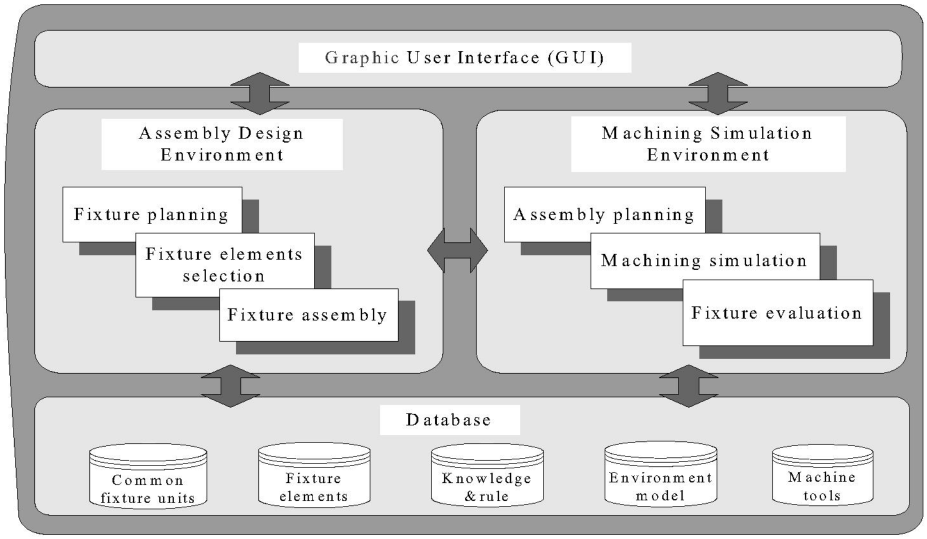


Fig.1. Overview of the desktop VR based modular fixture design system.

3) Database: The database deposit all of the models of environment and modular fixture elements, as well as the domain knowledge and useful cases. There are 5 databases shown in Fig.1. Among them, knowledge & rule base governing all fixture planning principles forms the brains of the system.

III. PROCEDURE OF MODULAR FIXTURE DESIGN

In this section, an instructive modular fixture design procedure within VE is presented. Besides the 3D depth that the users feel and the real-world like operation process, this procedure features intelligence and introduction. During the design process, some useful cases and suggestion will be presented to the user for reference based on intelligent inference method such as Case based reasoning (CBR) and Rule based reasoning (RBR). Further more, relative knowledge and rules are presented as help pages that the user can easily browsed during the design process.

Overview of modular fixture design process is summarized in Fig. 2. After the VE environment is initialed and the workpiece is loaded, the first step is fixture planning. In this step, the user first decides the fixturing scheme, that is specifies the fixturing faces of the workpiece interactively. For help the user's decision-making, some useful cases as well as their fixturing scheme will be presented via the automatic CBR retrieval method. Once the fixturing faces are selected, the user may be prompt to specify the fixturing points. In this task, some suggestions and rules are given.

After the fixturing planning, the next step is fixture FUs design stage. In this stage, the user may be to select suitable fixture elements and assemble these individual parts into FUs. According to the spatial information of the fixturing points in relation to the fixture base and the workpiece, some typical FUs and suggestions may be presented automatically. These will be helpful for the user. After the planning and FUs design stage, the next stage is interactively assembling the designed fixture FUs to connect the workpiece to the baseplate.

When the fixture configuration is completed, the result will be checked and evaluated within the machining environment. The tasks executed in this environment including assembly planning, machining simulation, and fixture evaluation. Assembly planning is used to gain optimal assembly sequence and assembly path of each component. Machining simulation is responsible for manufacturing interaction detection. Fixture evaluation will check and evaluate the design result. In conclusion, the whole design process is in a nature manner for the benefit of VE. Moreover, the presented information of suggestion and knowledge can advise the user on how to make decisions of the best design selection.

IV. ASSEMBLY MODELING OF MODULAR FIXTURE

A. Modular fixture structure analysis

A functional unit (FU) is a combination of fixture elements to provide connection between the baseplate and a workpiece [11]. Generally, modular fixture structure may be divided into three functional units according to its basic structure characteristics, namely locating unit, clamping unit, and supporting unit. The number of fixture elements in a FU may consist of one or more elements, in which only one element serves as a locator, support or clamp. The major task of the modular fixture assembly is to select the supporting, locating, clamping and accessory elements to generate the fixture FUs to connect the workpiece to the baseplate.

By analyzing the practical application of modular fixtures, it is found that the assembly of modular fixtures begins by selecting the suitable fixture elements to construct FUs, then subsequently mounting these FUs on the baseplate. Therefore, the FUs can be regarded as subassemblies of modular fixture system. Further, the structure of modular fixture system can be represented as a hierarchal structure as shown in Fig.3.

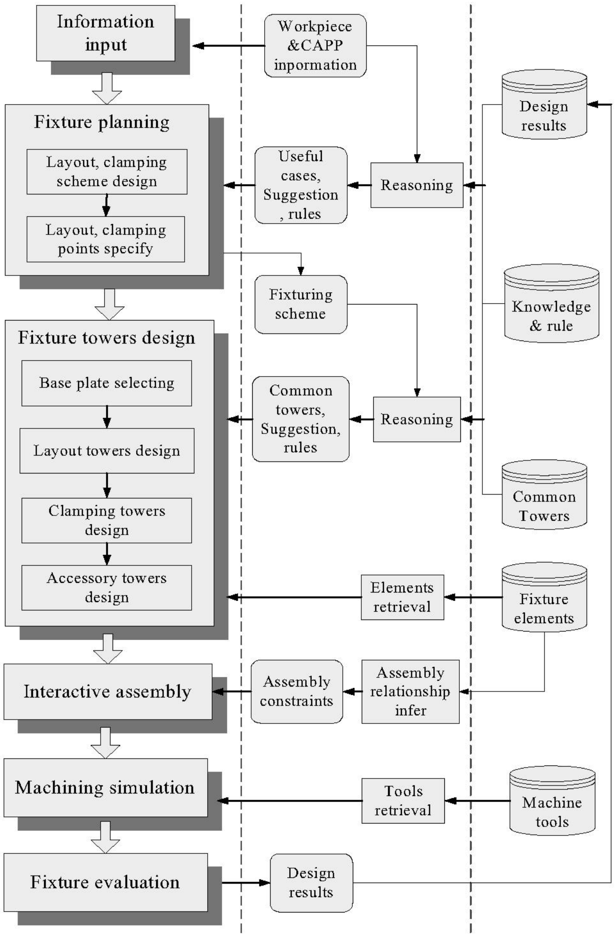


Fig. 2 Modular fixture design procedure in proposed system

B. Hierarchically structured data model for modular fixture representation in VE

It is common that the corresponding virtual environment may contain millions of geometric polygon primitives. Over the past years, a number of model sub-division schemes, such as BSP-tree [10] and Octrees, have been proposed to organize large polygonal models. However, for modular

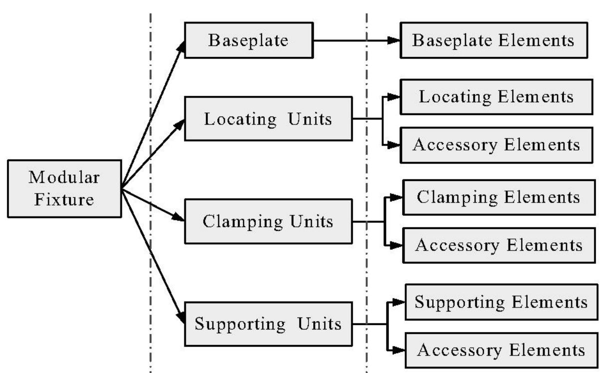


Fig. 3 Hierarchical structure of modular fixture system

design applications, the scene is also dynamically changing, due to interactions. For example, in design process, the part object may change its spatial position, orientation and assembly relations. This indicates that a static representation, such as BSP-tree, is not sufficient. Further more, the above models can only represent the topology structure of fixture system in the component level. However, to the assembly relationship among fixture components, which refers to the mating relationship between assembly features that is not concerned. In this section, we present a hierarchically structured and constraint-based data model for modular fixture system representation, real-time visualization and precise 3D manipulation in VE.

As shown in Fig.4, the high-level component based model is used for interactive operations involving assemblies or disassembles. It provides both topological structure and link relations between components. The information represent- ed in the high-level model can be divided into two types, i.e. component objects and assembly relationships. Component objects can be a subassembly or a part. A subassembly consists of individual parts and assembly relationships between the parts.

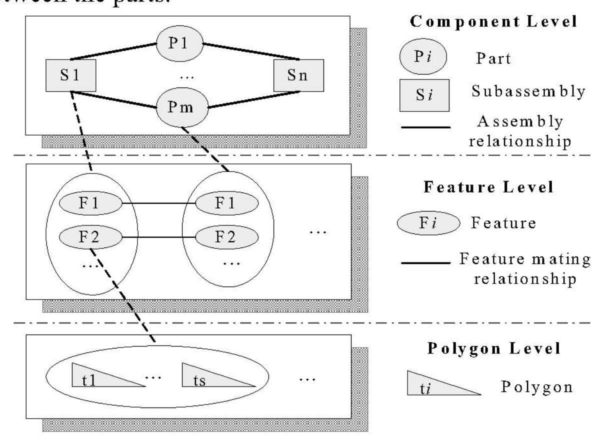


Fig. 4 The hierarchical structure data model in VE

The middle-level feature based model is built upon features and feature constraints. In general, the assembly relationship often treated as the mating relationships between assembly features. Thus the feature based model is used to describe the assembly relationship and provides necessary information for spatial relationship calculating during assembly operation. In this model, only the feature relationships between two different components are considered. The relationship between features of one element will be discussed in feature based modular fixture element modeling below.

The low-level polygon based model corresponds to the above two level models for real-time visualization and interaction. It describes the entire surface as an inter-connected triangular surface mesh. More about how the polygons organized of a single element will be discussed is the next section.

C. Modular fixture elements modeling

As we know, in VE, the part is only represented as a number of polygon primitives. This result in the topological relations- hips and parametric information are lost during the translation process of models from CAD systems to VR systems. However, this important information is necessary in design and assembly process. In order to fulfill the requirements, we present a modeling scheme for fixture elements representation in this section.

The modular fixture elements are pre-manufactured parts with standard dimensions. After the fixturing scheme designed, the left job is to select suitable standard elements and assemble these elements to form a fixture system in a feasible and effective manner. Therefore, in the proposed system, only the assembly features of the fixture elements need to be considered.

In this paper an assembly feature is defined as a property of a fixture element, which provides related information relevant to modular fixture design and assembly/disassembly. The following eight function faces are defined as assembly features of fixture elements: supporting faces, supported faces, locating holes, counterbore holes, screw holes, fixing slots, and screw bolts. Besides the information about the feature like type and dimension, other parameters, i.e. the relative position and orientation of the feature in the element's local coordinate system are recorded with the geometric model in the fixture element database. When one element assembles with another, the information about the mated features is retrieved and used to decide the spatial relationship of the two elements. More information about the assembly features and their mating relationship are discussed detailed in Ref [11].

D. Constraint based fixture assembly in VE

1) Assembly relationship between fixture elements

Mating relationships have been used to define assembly relationships between part components in the field of assembly. According to the assembly features summarized in the above section, there are five types of mating relationships between fixture elements. Namely against, fit, screw fit, across, and T-slot fit, which are illustrated in Fig. 5. Based on these mating relationships, we can reason the possible assembly relationship of any two assembled fixture elements.

2) Assembly relationship reasoning

In general, the assembly relationship of two assembled part is represented as the mated assembly feature pairs of them. In the above section, we defined five basic mating relationships between fixture elements. Therefore, it is enabled to decide the possible assembly relationships through finding the possible mating assembly feature pairs. These possible assembly relationships are saved in assembly relationships database (ARDB) for fixture assembly in next stage.

However, when the fixture is complicated and the numbers of composite fixture elements is large, the possible assembly relationships are too much to take much time for reasoning and treating. To avoid this situation, we first decide the possible assembled elements pairs. That is to avoid reasoning the assembly relationship between a clamp and the baseplate, for they never were assembled together. In this stage, some rules are utilized to find the possible assembled elements pairs.

The algorithm of assembly relationships reasoning is similar to what discussed in Ref [12]. Thus the detailed description of the algorithm is omitted from this paper.

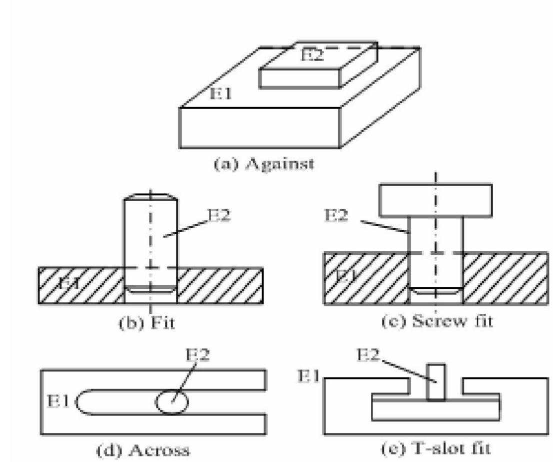


Fig. 5 Five basic mating relationships between fixture elements

3) Constraint-based fixture assembly

After carrying out the assembly relationships reasoning, all possible assembly relationships of the selected elements are established and saved in ARDB. Based on these relationships, the trainee can assemble these individual parts to a fixture system. This section is about the discussion of interactive assembly operation in VE. The process of a single assembly operation is presented in Fig.5 and illustrated by two simple parts assembly as shown in Fig.6.

In general, the assembly operation process is divided into three steps, namely assembly relationship recognizing, constraint analysis and applying, constraint-based motion. Firstly, the trainee selects an element and moves it to the assembled component. Once an inference between the assembling and assembled component is detected during the moving, the inferred features is checked. If the two features is one of the assembly relationships in ARDB, they will be highlighted and will await the user's confirmation. Once it is confirmed, the recognized assembly relationship will be applied by constraint analyzing and solving, that is adjust the translation and orientation of the assembling element to satisfy the position relationship of these two components, as well as apply the new constraint to the assembling element. When the new constraint is applied, the motion of the assembling element will be mapped into a constraint space. This is done by transferring 3D motion data from the input devices into the allowable motions of the object. The constraint-based motion not only ensures that the precise positions of a component can be obtained, but also guarantee that the existing constraints will not be violated during the future operations. The assembling element will reach to the final position through succession assembly relationship recognizing and constraint applying.

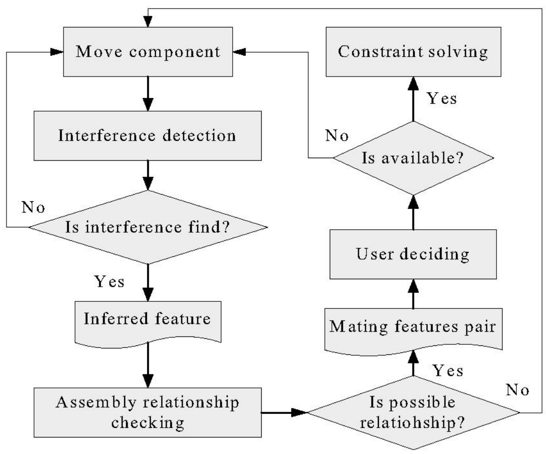


Fig. 6 Process of assembly constraint establishment

V. MACHINING SIMULATION

A. Manufacturing interactions

During the machining process, there are many types of manufacturing interactions associated with the fixture may occur. These interactions can be divided into two broad categories illustrated below, namely static interactions and dynamic interactions.

1) Static interactions refer to the interference between fixture components, the interference between fixture components and machine tool, and the interference between fixture components and maching feature of workpiece during the workpiece setup.

2) Dynamic interactions refer to the tool-fixture interactions, which occur within a single operation when the tool and the fixture used in that operation may collide during cutting.

Generally, the aspects of machining process and cutter paths are not considered during the fixture design stage. As a result, these interactions may often occur during the practical manufacturing. Thus the human machinists have to spend much of their time identifying these interactions and resolving them. It is often results in modification or re-design of fixture system. That is tedious and time costly.

B. Interference detection

Although the currently commercial software, like VERICUT, can simulates NC machining to detect tool path errors and inefficient motion prior to machining an actual workpiece. It is available to eliminate errors that could ruin the part, damage the fixture, break the cutting tool, or crash the machine during the part programming stage. However, these software are expensive and oriented to NC programmer thereby not suitable for fixture designers.

During the fixture design stage, it should be ensured that the associated fixture interactions can be avoided. In this system, after the fixture configuration is complete, the machining simulation module is presented to the user to identify the interactions and resolve them.

Within the machining simulation environment, the 3D digital model of machine tool is presented. The can assemble the fixture components on the work bench and setup the workpiece, just as what the machining engineers do in the actual site. During the setup, the fixture components and the workpiece are move to their assembly position under manipulation. The interference checking module is carried out. If interference occurs, the inferred object will be highlight. It is possible to adjust the assembly sequence or assembly path so that the interference can be avoided. However, if it can not, then the user must change the element or fixture unit.

After the workpiece setup, the movement of the cutter is simulated according to the generated cutting tool path from CAM system. For the benefit of VR, the solid, dynamic, 3D graphical representation allows for superior on-screen visualisation of the motion of the cutter. Therefore, tool path simulation allows the user close inspection and provides information of interference if occur.

VI. IMPLEMENTATION OF PROPOSED SYSTEM AND A CASE STUDY

A. Desktop VR system interface

In order to provide the end, the fixture design engineer, with a natural interface for more efficient design purposes. The GUI is designed with the reference to the immersive VR software by hiding most of the window's components. The GUI (Fig. 7) consists of a main VR display window, a right-hand toolbar and a bottom output status bar. The interaction between the system and the users is implemented via mouse and keyboard input. The toolbar provides the overall functions of developed system.

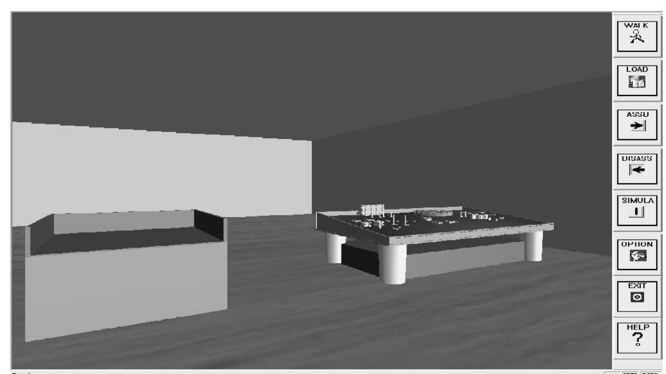


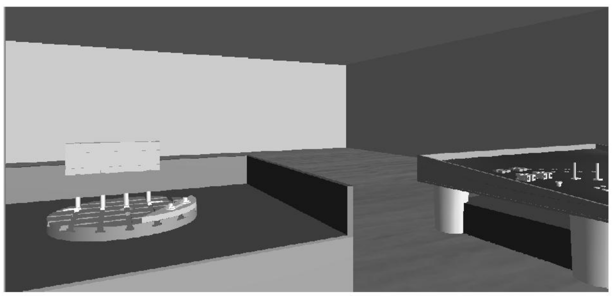
Fig.7 GUI of the proposed modular fixture design system

B. A case study

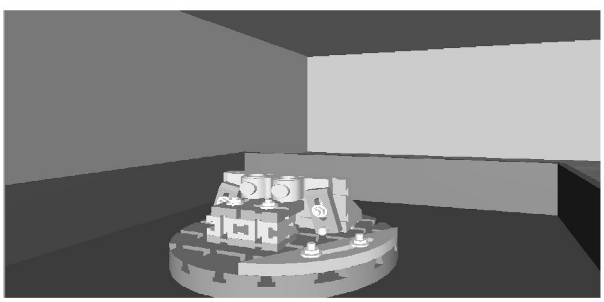
The developed desktop VR based modular fixture design system is explained with a case study. A workpiece to be machined is shown in Fig. 6. Face milling is to be performed on the top face, then followed by finishing the two counter-bore holes. The user designs a modular fixture system for this workpiece step by step with the guidance of the system. The fixture planning module has been applied to reach a feasible design solution efficiently. In this module, the locating, clamping and supporting faces, as well as the locating, supporting, and clamping points will be determined accordingly based on the ’s knowledge and the fixturing heuristic rules.

After that, the user explores in the elements depositing area and selects the appropriate fixture elements to fulfill the fixturing spatial requirement at various points. When finished, the user moves to the assembly design area and puts down the selected elements on the desk, as shown in Fig. 8(a). The next task is assembly the selected elements to complete the fixture configuration. In the virtual environment, the user can assemble the fixture elements in a natural manner. As shown in Fig. 8(b), the final configuration of modular fixture system for the example workpiece is formed.

When the fixture configuration is completed, the next phase is machining simulation for inference detection. As shown in Fig.9 (a) and Fig.9 (b), the constructed fixture system is mounted on the table of a CNC machine and the simulation of cutter path is executed.



(a)



(b)

Fig.8 Modular fixture assembly operation in a design scenario

Ⅶ. CONCLUSION

We have presented and developed a desktop virtual environment for modular fixture design towards manufacturing. The architecture of proposed system is presented and the virtual environment, namely assembly design environment and machining simulation environment is designed. Through analyzing the modular fixture structure, a hierarchical data module for assembly representation, as well as XML based fixture elements is presented. Thereby the precisely manipulation of virtual models in VE for modular fixture design and assembly is realized. Further, the assembly relationship between fixture elements is summarized and the assembly operation process in VE is described. The approach of machining simulation for manufacturing interaction checking is proposed. Finally a case study is presented to illustrate our integrate system.

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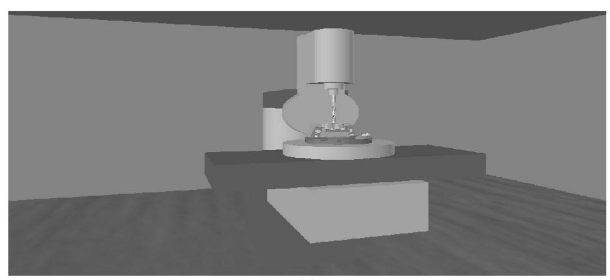
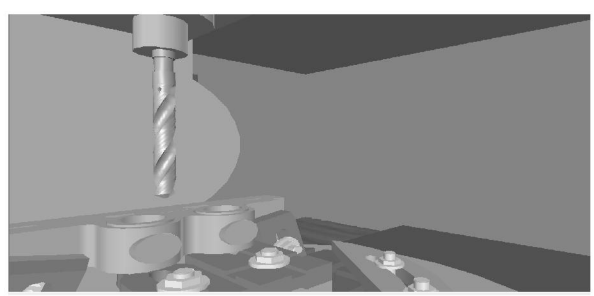


(a)



(b)

Fig.9 Machining simulation for interference detection