On The Way Toward Interactive Assembly Planning

Cheng Cheng, Feixiang Lan, Danjie Chen

Beijing Laboratory of Intelligent Information Technology, School of Computer Science,
Beijing Institute of Technology, Beijing 100081 PRC

Abstract

The assembly work constitutes a large percentage of the whole process of product manufacturing, assembly process planning is always one of the most difficult problems in manufacturing field. In this paper the authors will introduce a series of human centered thoughts and strategies on solving this problem which are realized in their prototype system. User’s intents are captured by both the modalities of hands and eyes; Multiple perceptions and two hand concurrent manipulations are designed to acquire the interaction semantics and to deal with the most difficult cases of assembly. A new assembly model is put forward to support 3D interaction, and the method of using the real design data in the system is also introduced.

1. Introduction

Assembly process planning prescribes the sequence and path details of assembly operations. An assembly plan has a large impact on production efficiency and costs [1]. Since assemblies have become increasingly complex, computer aided assembly planning (CAPP) has presented a considerable challenge to the engineers. The researches on this subject can be mainly classified, into algorithm based CAPP and interactive CAPP from the methodology perspective, or WIMP based CAPP and virtual environment (VE) based CAPP from the interface perspective. Homem de Mello and Sanderson represented all assembly plans explicitly using an AND/OR graph [2]. Thomas [3] and ZHA [4] used Petri nets to represent assembly planning. Kiam [5][6] used temporal logic to model assembly sequence. CAPP system which is based on WIMP interface has not been successful because assembly is dependent on a great deal of expert knowledge which has been proved very difficult to be formalized. Furthermore, for a given assembly, the number of feasible assembly sequences explodes exponentially as the number of components increases, this makes the automatic identification of a set of acceptable sequences being an extremely difficult task.

VE offers a potential for human beings to simulate the assembly process with consideration of all kinds of factors in product assembly and their knowledge [7]. Xiaobu Yuan introduced an interactive assembly planning work [8]. He acquired the precedence knowledge from user’s manipulation in virtual environment, and then established an assembly tree, from which a group of alternative assembly sequences were obtained. We have not seen any other paper that introduces the VE-based assembly process planning method, but it is obvious that this idea is gradually becoming a research direction, and more and more researchers will accept the thoughts. The authors of this paper will systematically introduce their practical work on this aspect from several critical facets.

Direct manipulation is a main operation manner of virtual assembly. 3D manipulations introduce human expertise into virtual assembly, we can get abundant static and dynamic information from them, and can use the useful information to serve every virtual assembly goal [9][10]. In order to support this idea, a model of product that can record the process of human-computer interaction is critically demanded. From this point of view, on one hand, assembly model should be the semantics model of interaction that reflects the user’s intention and the process of manipulation; On the other hand, the assembly model serves for many kinds of applications, it should integrate the whole facets of a product, and for every kinds of objectives instead of only for assembly planning [11]. So though many algorithms of planning can manage to acquire the planning without an integrated assembly model, it is considered to be difficult to integrate them into one system which is becoming pressing today. It is a demand to put forward a centric unified model which
can satisfy every aspect of requirements and has some good characteristics, such as non-redundancy and consistency etc..

2. Assembly planning by direct manipulation

The authors have used a strategy of computing based perceptions, the mode of user intent expressing and two hands concurrent assembly mechanisms to construct a harmonious human-computer interaction in the prototype system called Interaction3D, one of the goals of which is to acquire the assembly planning interactively.

2.1. Multiple Perceptions for Assembly Tasks

Traditional collision detection is pervasively used for virtual environment, but it is not feasible and effective for desktop virtual environment. The virtual assembly environment can use the parameters of the parts that have been modeled in design environment to facilitate 3D interaction by some means or other. A new perception mechanism to substitute collision detection method should be devised provided that the design data is used paralleled with VRML model.

The current used perceptions include feature matching perception, align constraint perception and face mating perception. According to the expert’s knowledge, the three perceptions are sequential and form a micro-cycle for interactive assembly process. For a complicated process, it may include several such kind micro-cycles.

On implementation aspect, the parts are considered as active objects, which switch states among different perceptions according to the current interaction scenario and have their particular corresponding visual representations which are helpful cues to the participants.

2.2. Catching user’s intents

The very interesting thing the authors discovered is that all user intents are expressed naturally with both eye gaze and hands manipulations. Real-time eye tracking is embedded in the prototype system Interaction3D. For a complicated situation, there are many different feature pairs matched each other at the same time, but only one pair is the one that the user wanted. The eye ray is used to select one such a feature from the target part.

![Fig.1. Perception mechanism in virtual assembly](image)

![Fig.2. Intent expressing and understanding](image)

The virtual space is discretized and temporalized first, and then series of scenarios are constructed also. The new multiple computing based perceptions are devised which considered the scenario and the user’s intents and using the design data to discover complicated spatial relationships among the objects. Fig.1 shows the mechanism of the multiple perceptions used in the prototype system Interaction3D.
The feature matching intent, as an example, is acquired by direct manipulation and eye selection. User moves a part beside a subassembly, aiming at matching two features that are on the current part and the target part. The user is at first required to approximately align the part, the perception function justifies whether two features are matched each other according to the types, the parameters and the directions etc for the pair. When the user moves the component, the features on the current component may match different features on the target component. For a complicated situation, there are many different feature pairs matched each other at the same time, but only one pair is the one that the user wanted. The eye ray is used to select one of the features matched in the target part, and user pushes a button to affirm the selection. The similar situation will occur in face mating intent capturing after the align constraint is satisfied. There may be many different face pairs matched each other at the same time. When mated faces are perceived, the representations of the matched faces on the target part will be emerged, user use eye ray to select the face which is the one wanted.

2.3. Two hands concurrent assembly

Two or three parts concurrent assembly is the most difficult task in assembly planning because it is not sequential but concurrent. Practice shows that interaction and animation should supplement each other for accurate manipulation. The most difficult thing of cooperative assembly is how to formalize the concurrent assembly process. Using the series of perceptions given above, and basing on the analysis of object behaviors, the assembly process is decomposed into temporal behavior segments at which the parts’ behaviors can be synchronized each other. Animation of active object is designed to assist the human’s manipulation. The constraint satisfaction is executed as a passage of animation. The two hand manipulation is shown in fig. 3.

It is possible to establish a kind of intelligent grasping, without the need to perceive the every point of finger touching. Flexible virtual hands are used in the system Interaction3D. Several gestures are constructed to suit for different kinds of grasping at different position of a part. Animation is used to assist the picking operation. The concurrent assembly algorithm described using temporal logic language is put forward and applied in the system.

3. Human centered assembly model

Assembly model is a structure of assembly in our system which will play a role of bridge between the users’ operation and the planning. The papers that related to assembly planning neither had discussed relations between direct manipulation and assembly planning, the relations between the user intent expression and interaction semantics construction, nor had considered how to integrate every aspect of application and human computer interactions into a unified system.

3.1. Assembly model for 3D interaction

The authors have firstly abstract aggregation and constraint dependency relationships from the complex working environment to depict human’s intents. Direct manipulation and multimodal interactions in VE can well express the user’s intents and embody an abundance of semantics. Current models haven’t elements that reflect these aspects; the authors secondly have given temporal relationships to record the temporal semantics of interaction. 3D direct manipulation is full of temporal semantics, while existing models neither have temporal elements nor have direct temporal description of the planning which can serve for different virtual assembly applications; the authors thirdly have introduced object trace as the dynamic part of assembly model, and combine the static part and the dynamic part as an organic whole. Some of the existing assembly models have only static description of assembly while the others have only dynamic description of assembly which have no relevance with any static information, it seems impossible to synthesize them, and if not, information redundancy and inconsistence are inevitable. On the other hand, the dynamic models of planning only have the capability of characterizing the discrete events, they haven’t record flow events, once the operation

Fig.3. Two hands concurrent assembly manipulation
finished, it is impossible to retrieve the process from them. Explicit description of the assembling process can well support assembly operations and planning.

Temporal aggregation relationship (TAR) is used to reflect the process of assembly composition where the parts are as building blocks; temporal dependency relationship (TCD) is used to reflect the process of adding constraints (CN) and to fast propagate the constraints. Also object trace is used to record the behavior of the objects in the assembly model. The trace is composed of a kind of short behavior sequence which is made up of three temporal behavior segments. A series of behavior concepts have specified to depict object behavior that is used to substitute the user’s interaction. The temporal assembly model structure is shown in fig.4.

3.2. Virtual Assembly Using the Real Design Data

At the present time, VRML format model is the standard of object model used by virtual environment. This kind of model only have the polygon information, based on which people then use collision detection strategy to interact with virtual object. It can not grant the demand of the people who use virtual assembly to deduce planning. On the other hand, there are countless designed parts for a company, how to use these designs in virtual environment is a big challenge.

As a part of the system Interaction3D, the authors have constructed a prototype subsystem which through parsing the STEP files retrieves the design information for the use of virtual assembly. From the wing-edge structure, the reasoning machine identifies every kind of features using the rules that are obtained. An algorithm is also constructed for abstracting the parameters that the authors need from the step files after the feature is recognized. The parameters include: ‘Origin’, ‘Major’, ‘Minor’, ‘3thAxis’, and ‘Origin_f’ which are called auxiliary features, respectively represent the center of a part or a feature, the three coordinate axes which are perpendicular with each other, the mating face of an assembly feature. The parameters such as length, width, height or radius of a feature are also be evaluated. The design information is then saved in XML files.

Currently the system can recognize several main features such as cylinder, block, slot, hole etc, fig 5. The authors’ idea is to solve the transition successively.
will be very complicated, it is impossible to recognize the features only by algorithms. Pen based interface is provided to let the user point out an unusual features on the VRML model and let the algorithm directly to search the features and give the detail analysis based on the user’s hint.

The new parts’ model is constructed in Interaction3D using this subsystem to retrieve the parts’ parameters. When a part’s data file and the VRML file are imported, the part objects and the VRML node are created. The part object and the VRML node mapping is established, the feature mapping between the part object and the set of polygons in the VRML model is made. Auxiliary features are created for every feature and last the behavior mechanism is added to the parts.

4. Planning derivation

Local modification refers to the little change to a few parts in the assembly without disassembling and reassembling many other parts that have been assembled. During the whole assembly process, rework is inevitable. For a large assembly, the rework will be a fatiguesome and time-consuming job, backtracking the states of an assembly and automatic repetition during the process is needed for virtual assembly.

Some functions are built to make local modification. Function ‘DeletePart’ directly disassembles a part from an assembly without manipulating any other parts in the assembly and also move the other parts that have been assembled after the deleted part, the constraints needs to be adjusted and satisfied so as to let all parts be fixed in their right positions; function ‘AddPart’ inserts a part to the assembly at the same position where it had been interactively assembled. Just like the function ‘DeletePart’, this function is responsible for re-satisfy the constraints of other parts; ‘Auto-Assemble’ and ‘Auto-Assemble-All’ can reassembly a part or the whole components automatically according to the previous direct manipulations respectively, whereas ‘Auto-Disassemble’ and ‘Auto-disassemble-all’ are the reverse operations of ‘Auto-Assemble’ and ‘Auto-Assemble-All’ separately.

The remaining problem of local modification is how to make the part relocated when the circumstance changed. The main idea of the algorithm is to find the potential feature that will be matched instead of the original feature from the dependency network and then to perceive the new constraints to update the assembling trace.

With the facilities of local modification, from the temporal model it is easy to derive assembly sequences and assembly path which are the main content of assembly planning. The parameter ‘i’ in the temporal aggregation relations explicitly tells a sequence. We are convinced that this sequence is reasonable and feasible though it may not be the optimal, provided that the user of this system is professional. In the virtual environment the user can continually optimize the sequence through local modification operation and finally approach the goal with some evaluation metrics. The assembly trace is actually the assemble path, which not only include the insert direction but also include the detail information about the path from the place the part lies at the beginning to the final place the part is fixed in the assembly. The object’s trace of a part which has been created during the manipulation process is just the assembly path. This not only has solved the problem of application integration but also has provided a concrete realization of user centered design.

4. Conclusion

This paper has introduced the prototype system Interaction3D, the goal of which is to construct a harmonious virtual environment for the assembly planner. The characteristics include several perceptions and intents capturing, concurrent assembly, temporal assembly model. Practices show that the mechanism of human centered planning in Interaction3D can acquire feasible assembly plan and have large potential in user’s intent understanding and semantics construction. In the future, interactive analysis of the STEP files will be on investigation. The modes of eyes corresponding with hands will be investigated more deeply. Temporal assembly model based planning algorithms will also be put forward.

5. Acknowledgment

This work is jointly supported by national natural science foundation of China (No.60773046) and national 863 project (No. 2006AA01Z120).

6. References


