Constraint-Based Inference of Assembly Configurations *

Federico Thomas and Carme Torras

Institut de Cibernètica (UPC-CSIC)
Diagonal 647, 08028-Barcelona.
SPAIN.

Abstract

A system for the automatic synthesis of assembly configurations is presented. It consists of the propagation, combination and satisfaction of three types of constraints: *shape-matching* constraints, constraints *on the degrees-of-freedom* and *non-intersection* constraints.

Given a high-level description of an assembly and the models of the workpieces, the system determines which parts of the workpieces should be mated and produces a set of homogeneous-coordinate transformations defining the relative position and orientation of each workpiece in the final assembly. This system can be seen as a previous step towards a practical and efficient assembly planner.

1 General framework

The method described in this paper for the automatic inference of final assemblies is embedded in the planner described in [1]. The part of the planner described here is confined to obtaining the spatial relationships between workpieces in the final assembly, from an initial description consisting of the models of the workpieces and, if necessary, disambiguating instructions which specify constraints on the degrees of freedom (d.o.f.) between parts of the workpieces.

We have adopted a constraint-based approach to solve the problem, in which the process of synthesizing assembly configurations is conceived as a progressive refinement of an initial description by the application of successive constraints. These constraints are of three types: (1)*shape-matching constraints* between the mating parts of the workpieces to be assembled (complementary shape and similar parameters); (2) *constraints on the degrees-of-freedom* (d.o.f.) between the parts of the workpieces; and (3) *constraints of non-intersection* between workpieces. The first two types reduce the dimensionality of the space of d.o.f. of the workpieces (that is, the space of assembly configurations or *configuration space*), while the third type eliminates from configuration space the zones that lead to interferences. The remaining configurations after carrying out all the reductions and eliminations implied by the different constraints will be the solutions to the problem.

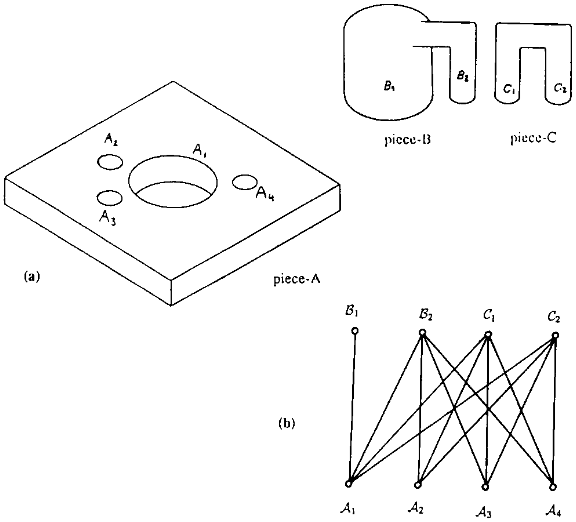

Fig. 1 (a) *Simple assembly problem* **(b)** *Associated graph of compatibilities between features.*

2 Shape-matching constraints

The first step in the process is the extraction of all relevant *features* of the involved workpieces, according to a dictionary of possible features [4]. Afterwards, *matchings* between features are established, leading to a graph of compatibilities between features (GF graph).

The developed system takes into account *"graded"* shape-matching constraints, that is, those involving concavities and convexities that do not exactly match each other.

Once the GF graph has been created, the control of the system looks for an optimal matching between workpieces. This problem can be conceptualized as a graph matching problem [7]. Obviously, in this case, optimality is not always a guarantee of feasibility. Note that the matchings between features have a direct translation into constraints on the d.o.f. leading to a graph of spatial relationships, or GR graph, and these constraints must be also satisfied. This is best shown through an example.

Fig. 1(a) shows three workpieces to be assembled and *fig. 1(b)* the graph of compatibilities between their features. Once an optimum is obtained, compatibilities in the matching of the GF graph are translated into a GR graph, whose consistency is checked as described in the next section.

---

*This work has been partially supported by the grant CA 83/188 of the US-Spain Joint Committee for Scientific and Technological Research.

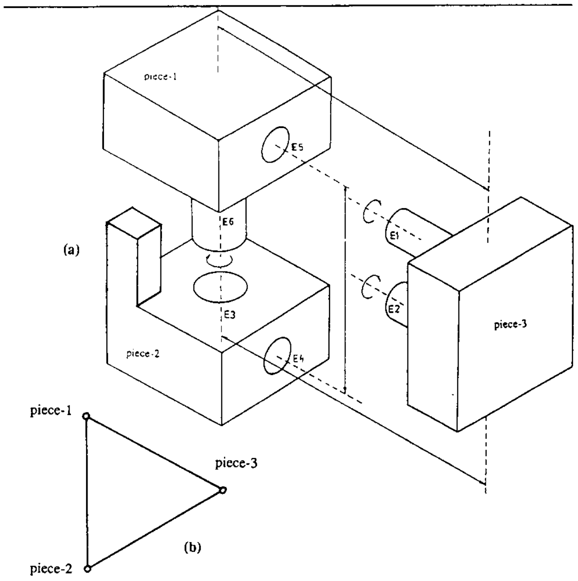

Fig. 2 **(a)** *Example used to show how constraints on the d.o.f. are posted* **(b)** *Associated graph of spatial relationships.*

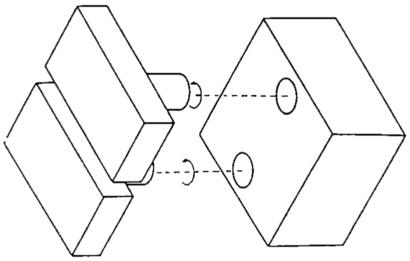

Fig. 3 *Example used to show the kinds of problems associated with non-intersection constraints.*

3 Constraints on the degrees of freedom

The propagation and satisfaction of constraints on the d.o.f. allow us to obtain the spatial relationship between two workpieces, given - for instance - a set of relationships between their features. Previous attempts to deal with these constraints have arisen in two domains: mechanics and object-oriented programming languages for robots. The procedure followed by our system to deal with this kind of constraints is fully explained in [8].

An example is given in *fig. 2(a)*. Let us assume that the shape-matching constraints lead to the alignment of the pairs of axes $(E1, E5)$, $(E2, E4)$ and $(E3, E6)$. When these constraints on the d.o.f. are inserted in a GR graph (*fig. 2(b)*), a cycle of length three is detected and a chain of matrix products with six variables is extracted;

Notice that the final configuration satisfies all shape-matching constraints and constraints on the d.o.f., but, because of intersection problems, it is still unfeasible.

4 Constraints of non-intersection

Two types of interference checking can be clearly distinguished: the detection of intersections between objects in fixed positions and the detection of collisions between objects moving along specified trajectories. The configuration problem tackled here, despite its static nature, has to be viewed as an instance of the second type of checking. The reason for this is the possible existence of d.o.f. for the workpieces, along which we have to find interference-free locations.

A good way to represent these constraints is by using the Configuration Space (C-Space). The main problem concerning C-Spaces is their construction because of the computational effort involved. Thus, it is very important to avoid its explicit representation. Moreover, since clearances between workpieces, in the assembly domain, can be arbitrary small, an exact representation of the boundaries and obstacles in the C-Spaces is required.

Our procedure follows the typification of constraints stated in [6], which is framed within a predicate-based approach as in [2]. Two algorithms have been developed: one concerning a simplified representation of C-Spaces, and the other related to the development of local experts, as in [3], in order to solve some interference problems without explicitly building C-Spaces.

An example using this kind of constraints is given in *fig. 3*. In this figure, there are three workpieces, two of them still having one d.o.f., which is limited to ranges of values due to constraints of non-intersection. The lower the clearances between them, the greatest the resolution in the C-space must be to find intersection-free configurations.

Conclusions

We have briefly presented a constraint-based method to infer assembly configurations, as well as specialized techniques to deal with each constraint type.

The method has been devised so that it can be very easily extended to deal with new constraint types. Thus, the obvious extension is the addition of a new operator for dealing with *sequencing constraints* [5]. This would allow the system to distinguish those configurations for which there is a feasible assembly sequence from those for which, despite satisfying all other constraints, there is no such a sequence.

References

[1] L. Basañez, R.B. Kelley, M. Moed and C. Torras, "A least-commitment approach to intelligent robotic assembly," *This Conference.*

[2] J. Canny, "Collision detection for moving polyhedra," *IEEE Trans. on PAMI*, vol. 8, num. 2, pp. 200-209, March 1986.

[3] B.R. Donald, "Global and local techniques for motion planning," *Master Thesis*, MIT, Cambridge, Massachusetts, 1984.

[4] M.R. Henderson, "Extraction of feature information from three dimensional CAD data," *PhD. dissertation.* Purdue University, 1984.

[5] W. Jentsch and F. Kaden, "Automatic generation of assembly sequences," *Artificial Intelligence and Information-Control Systems of Robots*, edited by I.Plander, Noth-Holland: Amsterdam, 1984.

[6] T. Lozano-Pérez, "Spatial planning: A configuration space approach," *IEEE Trans. Comput.*, vol. C-32, pp. 108-120, Feb. 1983.

[7] C.H. Papadimitriou and K. Steiglitz, "Combinatorial optimization: Algorithms and complexity," Prentice-Hall Inc. 1982.

[8] F. Thomas and C. Torras, "A group theoretic approach to the computation of symbolic part relations," *IEEE Journal of Robotics and Automation* (to appear).