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A novel approach to the geometric feasibility analysis for fast assembly tool reasoning

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Abstract A product assembly or disassembly is completed by means of proper tools. The selection of feasible tools is an important process in planning a complete assembly or disassembly sequence. A key tooling consideration in assembly or disassembly planning is to reason the available space for a tool application during the assembly or disassembly of a product. Currently, assembly tool reasoning about space mainly depends on simulation-based or user-interactive approaches because of its computational complexity. These approaches are inappropriate in dealing with various what-if scenarios regarding assembly or disassembly planning in a rapid product development. They also depend on users’ expertise or experience in assembly or disassembly. This paper presents a novel approach to the geometric feasibility analysis for fast assembly tool reasoning. Techniques described in this paper are advantageous not only in the aid of generating a complete assembly or disassembly plan but also in the efficient support of such systems as computer-aided assembly planning (CAAP), design for manufacturing (DFM), design for assembly (DFA), design for disassembly (DFD), and computer-aided tool selection (CATS).

Keywords Fast assembly tool reasoning · Geometric feasibility analysis · Global accessibility cone with depth

1 Introduction

The proper tool is the key to complete a product assembly or disassembly. Tooling is an important factor in planning a complete assembly or disassembly sequence. An incomplete plan generated for product assembly or disassembly may lead to re-tooling, special tooling, or design changing at the production stage. A key tooling consideration in assembly or disassembly planning is to reason the available space for tool applications during a product assembly or disassembly.

Compared to other reasoning methods developed for tools in machining or measurement, assembly tool reasoning about space is a relatively under-explored issue. Moreover, some existing methods are computationally expensive to implement. Current assembly tool reasoning about space is mainly executed via physical or virtual simulation, or interactive user-knowledge. These approaches are not efficient in dealing with various what-if scenarios regarding assembly or disassembly planning in a rapid product development. They also tend to depend on users’ expertise or experience.

Over the past decade, competitive market and technological innovation have continuously driven industry to pursue higher performance structures in design and manufacturing. One of the structures is known as distributed concurrent engineering (CE) or collaborative design and manufacturing system [1]. Instead of the traditional process of product development, which is procedural and highly iterative, a high performance design and manufacturing system is defined by following key terms, ‘dynamic’, ‘concurrent’, ‘distributed’ and ‘collaborative’. There is a demand for a fast assembly tool reasoning in the high performance of design and manufacturing systems to achieve the above paradigms. The assembly tool reasoning under the design and manufacturing system should enable to deal with a large number of possible tool sets needed for an assembly or disassembly operation, and to efficiently integrate with other systems: design for manufacturing (DFM), design for assembly (DFA), design for disassembly (DFD), computer-aided assembly planning (CAAP), computer-aided tool selection (CATS) and dynamic tool resource planning and scheduling. These requirements generated the motivation of this research.

This paper focuses on the geometric feasibility analysis for a fast assembly tool reasoning. Given solid models of product parts and fasteners, the goal is to quickly determine whether an assembly tool is feasible or not. In addition,
a system linked with database (DB) is implemented to achieve a fast assembly tool reasoning in a dynamic manufacturing environment. After selecting feasible tools based on such constraints as a given part configuration, a fastener type and tool availability in a dynamic shop floor, the system can also simulate the tool applications on a computer generated three-dimensional (3D) environment. The simulation can clearly verify that the tools are appropriate in assembling or disassembling a fastener.

2 Literature review

There have been many attempts to incorporate assembly tool reasoning into assembly or disassembly planning. In the research performed by Mello and Sanderson, attachments were included in a relational model of assemblies for fastening operations [2]. Although the attachments can be used to plan an assembly or disassembly sequence, the detailed tool applications required to remove these attachments were not modelled in their work. Miller and Hoffman [3] described a system that requires the access space for a fastener removal. However, the simple tests consisting of ray casting and box tests were used to roughly distinguish between feasible and infeasible tool applications.

The most detailed work was examined by Wilson [4]. The author developed a tool representation that includes the tool use volume, the minimum space that should be free in an assembly to apply the tool. In his research, the author also mentioned the notion of fast tool reasoning that allows selection of a tool from a set of possible tools to execute an assembly operation. However, his approach requires the computation of the configuration space (C-space) representation of obstacles, which is very expensive in dealing with variations in place constraints and use volumes. Practically, the variations commonly occur even if a simple tool is applied to a fastener, such as a screwdriver or an open-end wrench. In addition, the C-space once created for a tool and obstacles may not be reused for examining another tool because of its drastic change according to tool type, size or degree of freedom (DOF). It is not appropriate to achieve our goal to deal with a large number of possible tool sets for a fastener, which are retrieved from an assembly tool DB.

Gupta et al. [5] proposed a method to avoid the expensive computation of the C-space. With the articulated tool representation, the method combines collision detection methods and randomised via-point path planners. However, the method was also based on the same assumption used by Wilson [4], where tool place constraints and use volumes are not variable during a tool application. Because of limitations of their method to deal with variations in a tool application, the feasibility of an assembly tool with 1-DOF is only discussed in their research.

Recently, Lazzcerini and Marcelloni discussed the importance of a number of assembly tools applied and tool changes in optimal assembly sequence planning [6]. However, the authors did not incorporate this notion into their work. Researchers such as Kuo [7], Tseng and Li [8] and Yin et al. [9] focused on fasteners in assembly or disassembly planning, but they also fail to notice assembly tools into their work, which may be feasible or infeasible for the fasteners in a given part configuration. In the research performed by Léon et al. [10], a fast sequence generator for assembly or disassembly was proposed to support the early design process of a product development. Although the authors discussed the significance of assembly tooling in generating an efficient assembly or disassembly sequence, no tool accessibility test was executed in their work. Moreover, Tseng et al. [11] incorporated a number of tool changes into their objective function used to plan an optimal assembly sequence. In their research, however, the authors only used four types of general tools classified by the applied force magnitude.

In this research, we adopt a modified global accessibility cone (GAC) to make tool assembly reasoning computation- ally inexpensive, instead of C-spaces or collision detections. The concept of GACs has been extensively investigated, and leads to promising results for the accessibility analysis of tools in many other applications such as multi-axis machining, laser scanning and coordinate measuring machine (CMM).

The notion of feature accessibility and technique for creating accessibility cones were first proposed by Spyridi and Requicha [12]. In their research, GACs were used to represent feasible angles of attack for a probe approaching an object. However, this method cannot generate accessibility cones for a general surface because of the computation complexity of their algorithm that is called Minkowski algorithm. As eliminating the need for the complex computation of Minkowski algorithm, approaches to create GACs at single points were suggested by many researchers [13–15]. They adopted various methods to efficiently create GACs such as a ray casting technique and Boolean operations. By exploiting standard computer graphics hardware, recently, discrete approximation techniques have been used to rapidly create GACs [16, 17].

As mentioned early, the concept of GACs is adopted in this research to define a modified GAC, which is here named the global accessibility cone with depth (GACd). The difference from normal GACs is that the GACd additionally includes depth information between obstacles and the centre point. It is advantageous in considering both external feasibility and internal feasibility that is based on complicated tool applications against obstacles.

The remainder of the paper is organized as follows: First, the GACd and tool representations used in the research are introduced in details. Next, we present a proposed methodology to analyse assembly tool feasibility based on the GACd. Then, several cases of assembly tool reasoning are experimented in the system developed in this research. Subsequently, a final section summarizes the paper, and draws conclusions and further work.