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Optimization of Assembly Sequence Plan Using Digital Prototyping and Neural Network

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Abstract

Carrying out assembly process planning tasks manually is both time-consuming and requires a lot of effort. To gain an insight into the processes that occur during a design and assembly task, time and motion study methods are utilized in both digital prototyping and assembly sequence programming to carry out the investigation. In addition, a brief investigation has been carried out to examine the time savings of using the virtual tools in comparison with the traditional manual method. The whole process comprised of three steps viz. digital prototyping, assembly representation i.e. assembly part relationships and generating optimized assembly sequence plans. The process resulted in 60% saving in time, 63% saving in assembly cost and 150% improvement in the productivity.

Keywords: Assembly, Sequence, Digital prototyping, Hinge Assembly.

1. Introduction

When a product is assembled, an assembly agent will follow a prescribed order to put components into a fixture to complete the final assembly of the product. This order is known as assembly sequence of the product. In order to determine required sequences, many researchers used assembly constraints because the explicit acquisition of the assembly constraints has several merits.

Assembly is one of the most cost effective approaches to high product variety. With proper design of a Product Family Architecture (PFA) [6], each functional module of the product is provided with several variants so that the assembly combination will provide high variety in the final products. Mechanical assembly features such as tolerance and kinematics may also be included in assembly representation [7]. A general constraint model was proposed to express process constraints more systematically and efficiently [5].
An ontology-based representation was proposed to identify differences in joints by using a region-based theory and semantic web rule language [3]. Disassembly was also used widely either to analyze assembly sequence [2].

The disassembly sequences are then generated following certain distinct rules. One common thread that appears in most of these works is the strategy of “assembly by disassembly” in which an assembly sequence is generated by starting with the complete product and working backwards through disassembly steps [2]. The disassembly procedure is less complex than the assembly procedure. The backward assembly planning is based on one assumption that each part is rigid because the inverse of a disassembly sequence is equal to an assembly sequence only if each part is rigid. This research work presents a methodology for the generation of assembly sequences that is correct and complete and applied to most complex aerospace mechanisms used in satellite for communication. The correctness of the algorithm is based on the assumption that it is always possible to decide correctly whether two subassemblies can be joined, based on geometrical and physical criteria.

Digital prototyping provides tremendous time savings in making fully functioning physical models of very high complex internal and external geometry directly and automatically from CAD files [1].

A satellite is something that goes around and around the earth or another planet. Some satellites are natural, like the moon, which is a natural satellite of the earth. Other satellites are made by scientists and technologists to go around the earth.

The obvious and most convenient source of power would be to harness the Sun’s solar energy. Thus, all the satellites have their own set of panels of solar cells that trap the Sun’s rays and produce solar energy. Solar panels are in stow condition during launch and deploys them once the satellite is put into orbit. Post release in orbit it provides a smooth, controlled deployment. This deployment mechanism called as “Solar Array Deployment Mechanism” (SADM).

The SADM [6] consists of following assemblies. 1. Hinge assembly 2. Hold Down assembly 3. Release Assembly 4. Loop End assembly 5. Router pulley assembly 6. Corner bracket 7. Stopper assembly 8. Pyro cutter assembly. The hinge assembly is considered for development of assembly sequence optimization plan as it consists of 34 parts (BOM is Maximum of all other assemblies). The hinge assembly comprises of five subassemblies as shown in Figure 3.

To identify optimized ASP (Assembly Sequence Plan) following methodology was adopted: 1. Component CAD models – using digital prototyping 2. Perform the assembly of the component in the virtual environment. 3. Identify assembly procedures from the logged data. 4. Perform assembly of the physical hinge assembly 5. Giving output of digital prototyping as input to MATLAB through neural network programming and experience/knowledge based sequence planning 6. Finding optimized ASP.

2. Role of Digital Prototyping in Assembly Sequence Planning

A single assembly task involves joining two or more components or subassemblies together. In many cases, the order in which these tasks are performed is an important consideration.

Generating assembly sequence plans initiates with the drawing and 3 D model of the parts and the product. The use of inventor (part of digital prototyping framework of Autodesk Inc.) enabled the drawing of 34 parts of hinge assembly in 2 and 3 dimensions.

A digital prototype is a digital simulation of a product that can be used to test form, fit and function. According to F Zorriassatine [1], virtual prototyping is becoming very advanced and may eventually dominate the product development process. Physical prototyping can prove to be very lengthy and expensive, especially if modifications resulting from design reviews involve tool redesign [5].

Figure 1 shows 3-D assembly diagram of hinge drawn using digital prototyping software.
Figure 2 shows 3-D disassembly diagram of hinge drawn using digital prototyping software.
Digital Prototyping facilitated to bring together design data from all phases of the hinge assembly development process to create a single digital model. This single digital model simulated the complete product and gave the ability to better visualize, optimize and manage design before producing a physical prototype. It provided the interoperable tools required to identify create a complete digital prototype from the conceptual phase of a project through manufacturing. The critical part dimensions identified while carrying out the method study and these dimensions observed judgmentally during digital prototyping of bracket block washer bolt, mating-links, washer and bracket bolt. e.g. number of slots, slot length, slot radius etc.

According to Priyanka Mathad et. al., the digital prototyping has proved as effective tool for design and modeling of aerospace mechanisms like SADM [7].

3. Time and Motion Study

Gilbreth’s time and motion study has been successfully implemented in identifying assembly operations, such as positioning and assembling. By analyzing the therblig units associated with a process, unneeded movements have been eliminated to optimize a task and to generate an assembly process plan.

Bill-of-Material (BOM) generally lists all parts, subassemblies and materials, and also includes other information such as quantities, costs and manufacturing methods. The BOM has been a standard communication tool in industry for design, manufacturing and purchasing, and has been integrated to Computer-Aided Design (CAD) and Enterprise Resource Planning (ERP) systems. The BOM of hinge assembly consists of following 34 parts numbered from A-01 to A-34 [6].

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<td>A</td>
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<td>06</td>
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<td></td>
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<td>12</td>
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Table 1. Part Details of Hinge Assembly of SADM [6]
The time and motion study resulted in the following time dimensions of hinge subassemblies.


Eye end bracket assembly = A-013 → A-02 = 3 min

Critical sequence = A-017 → A-021 → A-020 → A-019 → A-026 = 13 min

Micro switch assembly = A-034 → A-033 = 12 min

Six possible sequences obtained after alteration of subassemblies of hinge assembly are shown in Figure 3.
4. Knowledge Based Approach to ASP

To save time and cost in assembly process and to improve the quality of products, it is very important to choose an optimal assembly sequence [4]. According to the kind of product and assembly circumstances, evaluation of assembly sequences requires various evaluation factors. But, because the existing studies have not sufficiently considered geometrical relationships and the degree of assembly difficulty, the evaluation are not only unsatisfactory but also applied only simple assembly problems [7].

In order to overcome the above problems, the developed system automatically generates subassemblies on the simple connect relationship information in some other way of the existing studies, and also prevent impractical and unnecessary processes by using disassembly methods with digitally prototyped model. To conduct this procedure smoothly, following assembly rules are developed, but it is only useful under a limited condition.

The concept of 3f’s (feature, function and format) is used to generate optimized ASP. First ‘f’ feature has been used for representation of the input data to the expert system shell. Template consists of a list of named fields called slots use to store various attributes and information. For example, the input data on a feature may be entered in the format of a template as shown in feature 1 (slot dimensions). Similarly feature 2 and is used to define the format for representation of the input data for contact relations, such as, the direction and whether the two parts are in contact or not in three principal directions. The input data on a typical feature may be entered as shown in feature 3.

Second ‘f’ stands for the function of the part. ‘Function 1’ used to find out the largest mass from the various mating parts the function calculates and compares all the components mass value and return the value of the largest mass. To calculate the total number of mating links, a function of the form can be used.

‘Function 2’ used to calculate the total number of mating links of a mechanical product hence to obtain the number of mating contacts for components with each other, and returns the value of total number of contacts for each component. The knowledge base of the expert system consists of assembly sequence planning in the form of rules.

Third ‘f’ calls for ‘format’ or ‘rule’ for ASP generation. A set of rules have been devised for selecting the base part and for assembly sequence generation between a pair of parts taking into account of the assembly precedence constraints.

Rule 1: Rule for selecting the component having largest mass among the various parts This rule selects the component having the largest mass compared to the other parts of the given product. Mating link is calculated using data contact function. The connectivity between the pair of components of the assembly can be expressed in terms of contact functions. Contact function ensures the presence or absence of contact between the pair of components. This can be obtained by finding the movement of components along the Cartesian coordinates only, e.g. +X, +Y, +Z, -X, -Y, -Z directions.

Rule 2: Rule for asserting the total number of mating links in each component. In order to identify the base part from a given set of components automatically, a set of rules have been devised based on heuristics and expert knowledge. A host of constraints are considered such as heaviest mass, number of contacts between parts for selecting the base part. Some heuristics rules for selecting the base part are given below.

- A part that is large and heavy in relation to the other parts is selected as the base-part
- The part which shares the most mating links with the others is taken as the base part
- The non-fastener part is also considered as the base part

Rule 3: Rule for selection of the base part during assembly The above rule selects the large and heaviest component as best fit for the base-part. Once the base-part for the assembly operation is selected, the other parts are considered successively for the assembly operation. Assigning the base-part as the first step of the assembly sequence, other components are assembled together one-by one satisfying all the constraints till the last component is assembled. The following rules are devised that illustrate an example of assembling between two components.

Rule 4: Rule for assembling two components in an assembly sequence

The above rule performs the following tasks,

- First selects the base-part as the first component to be assembled with the other components
- Identifies the second component next to be assembled that satisfies the contact relation constraint and stability constraint due to gravity
The part that satisfies the above constraints chooses as the second component and completes the subassembly with the first component.

**Rule 5:** Rule for assembling more than two components

The above stated rule performs the following tasks:
- First, it takes into account of the beforehand subassembly results between the two components
- Identifies the third component to be assembled that satisfies the contact relation, disassemble relation constraint, and stability constraint due to gravity
- The third component completes the subassembly with the earlier sub-assembled parts

The process continues till the last component is assembled.

5. **Output of MATLAB using Neural Network Programming**

The codes obtained from digital prototyping are fed as input to the MATLAB through neural network programming as shown in Figure 4. The program is prepared based on the 3 ‘f’ concept developed by knowledge based assembly sequence planning, discussed in section 4. The program can’t be provided in the section due to large number of codes.

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**Fig 4 Part details input to MATLAB**
Six possible sequences of parts of subassemblies are shown in Figure 5 as output of MATLAB.

![Fig 5 Output of MATLAB as six sequences](image)

The optimum sequence is selected that is possible to complete hinge assembly in 21 minutes as indicated in Figure 6.

![Fig 6 Optimized sequence of subassemblies for hinge assembly](image)

### 6. Conclusion and Discussion

An assembly sequence plays a key role in determining many important things in product assembly. The characteristics of a product, difficulty of product assembly, unit cost of a product and error rate are closely dependent on the selected assembly sequence. After digitization the error rate is reduced to 1 trial from 8 trials. The time taken for hinge assembly is reduced to 21 minutes from 53 minutes. The cost of hinge assembly is reduced to Rs. 233 from Rs. 637. Thus the previous productivity of assembly (2 sets per day) is improved to (5 sets per day). It was possible due to careful method study, product modeling and digitization of assembly process.
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References