Practically Feasible Optimal Assembly Sequence Planning with Tool Accessibility

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Abstract: Practically Feasible Optimal Assembly Sequence Plan (PFOASP) achievement is most important for an industrial engineer to meet the demand of producing the final product in less time and cost. A PFOASP directs the industrial engineer to generate a complete product with less number of manipulations from individual parts. An assembly sequence is said to be optimal from its nature of performing parallel operations to form stable subassemblies which directly reduces the overall assembly time for handling large scale products. Most the researchers followed to ignore tool accessibility in their approaches to avoid the computational complexities. However, the generated solution lacks completeness in practice because tools play the significant role while assembling operation. PFOASP determination is most challenging due to validation of multiple feasibilities qualifying criterion. In this paper, an attempt is made to explain the complexity and the importance of tool accessibility consideration in PFOASP with suitable illustrations. A tool based bounding box method is proposed to solve geometrical feasibility in PFOASP.

Key words: Assembly sequence planning, Liaison, Geometrical feasibility, Stability, Mechanical feasibility, Tool accessibility, Bounding box

1. Introduction:
Manufacturing industries are facing challenges in meeting the demands of producing new products in shortest time and less cost with their fabrication techniques. An industrial engineer is always paying effort to reduce the overall production cost and time of products to enter early into the market[1-2]. Researchers opinioned assembling a product was the significant time-consuming segment of the entire production process.

Assembling a product not only involves in bringing the individual parts together through a collision-free path but also maintaining its contact once positioned with the mating part and must allow for further joining operation[3-5]. So, a proposed assembly sequence must be optimal and practically feasible to save the time and cost in joining the individual parts in finished product generation. But PFOASP determination is most challenging due to validation of multiple assembly feasibility checking criteria. The criteria involved in the investigation of qualifying necessary assembly predicates such as liaison, stability, geometrical feasibility and mechanical feasibility. Several researchers investigated the importance of assembly predicate consideration for various assembly configurations [6].

Unfortunately, most of the researchers ignored tool accessibility consideration in their approaches to avoid the complexities of their implementation. Not only tool accessibility but also stability, mechanical feasibility has given less importance in assembly sequence generation problem. However, the generated solution lacks completeness in practice because tool accessibility plays the significant role in assembling operation. The next section composed to ascertain the background in PFOASP and importance of tool accessibility in assembly sequence generation.

2. Another section of your paper Back Ground of PFOASP:

Product data is extracted either in the matrix or graphical format to represent relations between the parts of an assembly. Assembly predicates such as liaison, geometrical feasibility, stability and mechanical feasibility to validate an assembly sequence for its execution in physical environment. But conventionally and recently most of the researchers supplementing few assembly predicates (stability and mechanical feasibility) in assembly sequence generation due to complexity in predicate consideration.

Smith made an attempt to represent part stability during assembly operation with any pairing part later Kumar and Bahubalendruni extended the concept and also proven assembly stability as a one of essential assembly predicate to result a practical possible solution. However, these concepts did not consider the involvement of assembly tool geometry and accessibility for establishing the assembly stability and mechanical feasibility in real time environment [7].

Unfortunately, researchers worked on DFA concepts and exploded view generation did not consider the involvement of assembly tool geometry and accessibility; though it is a key factor influence the cost and practicability [8-11].

Table. 1 presents assembly predicate consideration and tool accessibility consideration by numerous researchers in their approaches for ASP problem.

Table 1. Assembly predicates consideration from cited research literature

S. No.	Liaison	Geometric feasibility	Stability/ connection	Mechanical feasibility	Tool accessibility	Ref.
1	✓	✓	✗	✗	✗	[12]
2	✓	✓	✓	✗	✗	[13]
3	✓	✓	✓	✓	✗	[14]
4	✓	✓	✓	✓	✗	[15]
5	✓	✓	✓	✓	✗	[16]
6	✓	✓	✓	✗	✗	[17]
7	✓	✓	✓	✗	✗	[18]
8	✓	✓	✓	✗	✗	[19]
9	✗	✓	✗	✗	✓	[20]
10	✓	✓	✗	✗	✗	[21]
11	✓	✓	✗	✗	✗	[22]
12	✓	✓	✗	✗	✗	[23]
13	✓	✓	✗	✗	✗	[24]
14	✓	✓	✗	✗	✗	[25]
15	✓	✓	✗	✗	✗	[26]
16	✓	✓	✓	✗	✗	[27]
17	✓	✓	✓	✗	✗	[28]
18	✓	✓	✓	✗	✗	[29]

19	✔	✔	✔	✘	✘	[30]
20	✔	✔	✔	✘	✘	[31]

Though all predicates are considered in ASG, still the solution is lacking for completeness. Because a tool is essential to bring a component into contact and to establish a connection between two or multiple parts to develop a complete product. It is crucial to consider tool accessibility in ASG to make solution exist in practically feasible in the physical environment.

2.1. Assembly tools:
Assembly tools classified into three main types based on their application in assembly development and they are namely Pre tools, In tools and Post tools .
Pre tools: These are the tools used to bring parts together before the assembling operations. Often assembly fixture to hold the components are treated as Pre-tools.
Ex: Grippers
In tools: These are the tools used to move parts relative to each other and for simple snapping and insertions.
Ex: spanner
Post tools: These are the tools used operate the physical connectors after positioning the primarily parts.
Ex: Wrench, screw driver
On varying the combinations of tools addressed above, assembly operations are performed. Some configurations need only pre and post tools for assembling, CAD model of vertical axis wind turbine in fig.4.

3. Methodology:
Tool accessibility holds for verifying the collision-free path to the tool and appending part with other parts of the assembly. Tool accessibility is nothing but enriched geometrical feasibility testing which considers tool volume/tool swept volume and part volume instead of part volume only.

3.1. Bounding Box

Bounding box technique is the most popular method which is successfully employing for collision detection. A bounding box is a minimum cuboid receptacle for a part/assembly generated with edges parallel to the principal axes. The bounding box represented by two extreme diagonal points of the cuboid. Co-ordinates of the part bounding box are used to evaluate the distance to be progressed by a part of a specified orientation to complete an assembly operation. The difference between upper and lower limit elements along a principal axis direction is considered to examine the geometric feasibility of along it.
Tool volume and part volume consideration is enough to perform Pre and Post assembly operations.Fig.1 depicts the TA for pre and post assembly operations.
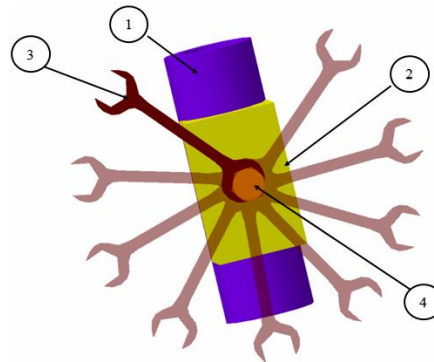
Fig.1. Tool accessibility for Pre and Post assembly operations

Tool volume, Part volume and the Swept volume of the tool during operation has to consider for inner assembly operations. Fig.2 depicts TA for Inner assembly operations.
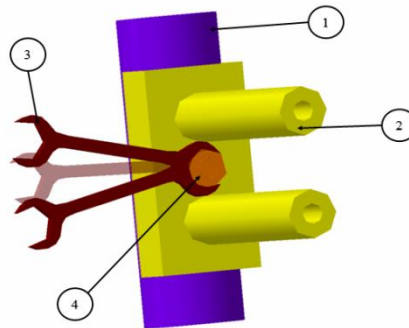

Fig.2. Tool accessibility for Inner assembly operations

3.2. Implementation

Tool accessibility predicate is implemented on two CAD models namely vertical axis wind turbine and switch board assembly represented in fig.3 and fig.4. Assembly sequences are generated with TA consideration and without consideration.
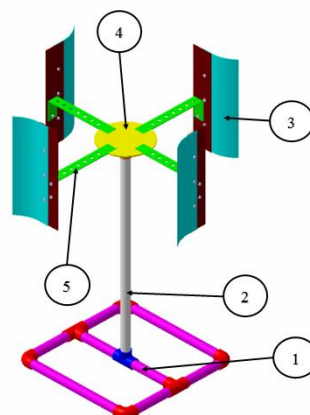

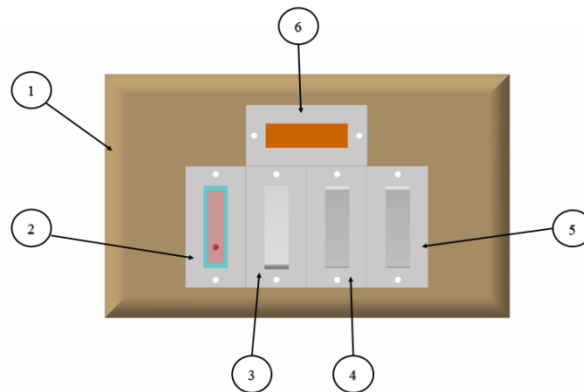Fig.3. CAD model of Vertical axis wind turbine

Fig.4. Switch board assembly

After implementing TA on preferred assembly model, results are presented in table 2 which explains the practical feasibility of the solution with and without TA.

Table.2. Influence of Tool Accessibility on PFOASP

Name of the assembly	Assembly sequence without TA	Assembly sequence with TA	Practical feasibility of sequence without TA
Wind mill	1-2-4-5-3	1-2-4-5-3	valid
Switch assembly	1-5-4-3-2-6	Not possible	Not valid

4. Discussions

Conventionally, researchers followed the consideration of connectors as parts of the assembly. But computational complexity issue raises with the increase in part count. Connection matrixes are used to represent type/presence of connection in an assembly instead of considering connectors considering directly/separately. However, these connection matrixes failed at explaining accessibility to install a connector between assembly parts. Later, Mechanical feasibility matrix used to represent the feasibility in establishing a connection between two different parts of an assembly among the presence of other parts. But Mechanical feasibility not conceded tool accessibility for placing a connector and assembly part.

Tool accessibility plays a crucial role in the case of restricted degrees of freedom between subassemblies of an assembly. Assembly sequence generation for Switch assembly is such a case which directly explains the error in ASG without considering tool accessibility predicate.

5. Conclusion

In this article, a novel tool based bounding box method is proposed to examine tool accessibility to perform assembly operations. It is observed that without considering tool assembly one may not achieve practical solution for all assembly configurations. Consideration of this assembly predicate may increase complexity and reducing solution space but practicality is achieved. Tool accessibility predicate consideration enriches the quality of solution enormously in PFOASP generation. Still, the efficiency of solution is limited because testing of assembly predicated confined to principal axis only. Space for assembling a product is more by performing in oblique directions too. Future scope of this research is to cover the identified issues in PFOASP.

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