A Scheduling Framework for Robotic Flexible Assembly Cells

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Abstract
Today's companies develop flexible systems that are adaptable to assemble a mix of products with minimal reconfiguration. A Robotic Flexible Assembly Cell (RFAC) is an adaptable system which can assemble a variety of products using the same resources. A major limitation of Scheduling RFACs is that no prior research has documented the scheduling problem for assembly of multi-products. Hence, the objective of the present study is to layout a scheduling framework to overcome this limitation. The framework intends to propose an effective way to solve the scheduling problem through modelling, simulation and analysis of the RFACs.

Keywords*: Scheduling, Simulation, Assembly Robots*

1 Introduction

Due to globalisation, two current attitudes have been developed in the manufacturing world. First, decreasing price and lead time are important to face competition. Second, because product life cycle is getting shorter and the demands of products are getting smaller, manufacturing companies need systems with the ability to react by mass customisation [1]. As a result, today's companies need to develop assembly systems that are flexible to assemble new products and mix of products with minimal reconfiguration. Flexible assembly systems (FASs) have the ability of simultaneously assemble a variety of product types of small to large batches. FASs can be divided, roughly, into two main types [2]:

- Robotic Assembly Line (RAL)
- Robotic Flexible Assembly Cells (RFACs).

RFAC has several advantages compared with RAL, particularly in flexibility and dexterity to assemble a variety of products using the same equipment. In addition, RFAC is easy to modify and reconfigure. Despite these advantages of RFAC, there has been no prior documented research of scheduling problem for assembly of multi-products. The aim of present study is to describe a scheduling framework that will enable RFAC to cope with assembly of multi-products concurrently.

2 Review of Related Studies

There have been few studies on scheduling RFACs which can be categorised into three approaches tabulated in Table 1 and explained below:

2.1 *Heuristic Approaches*

Heuristic Approach (HA) is an uncomplicated method to find reasonably good solutions, however it does not guarantee to find best solutions. Some studies have been dedicated to scheduling RFACs, using HA. For example, Nof and Drezner [3] proposed robot assembly planning and scheduling problem considering the allocation of assembly tasks. They formulated multi-robot operation as a multi-travelling salesmen problem. The purpose was to reduce the distance travelled. Lin et al [4]. dealt with the problem of Printed Circuit Board (PCB) assembly

They implemented an algorithm for simultaneous collision avoidance and scheduling operations, also to minimise assembly cycle time and consequently enhance the throughput. The algorithm was divided into three steps, initial insertion sequencing, balancing and re-assignment, and avoiding collision of robots. Another heuristic approach was presented by Pelagagge et al. [5] focused on assembly tasks characterisation to find the acceptable solutions for determining collision avoidance and coordination problems. They divided the assembly area into two categories, outside and inside workplace; the latter represents critical area. Jiang et al. [6] applied dynamic programming to solve the scheduling problem for a two-robot workcell; these robots operated concurrently to assemble one product. The aim of this work was to present algorithms for finding the optimal or semi optimal movement for each robot in the cell. Marian et al. [1] proposed a framework for integrating planning and scheduling of robotic assembly cell. Their system consists of two modules. The first is used to generate feasible optimal or near-optimal assembly sequence of each product. The second determines the priority of assembly operations for multi-products to use the available resources of the RFAC. The objective was to maximise the throughput of the cell

2.2 *Expert systems Approaches*

Expert systems (ES) are computerised tools that analyse a complex problem and recommends practicable solutions. In recent years, ES have been extensively used to solve scheduling problems in several domains; however only two studies have been devoted to solve scheduling of RFACs. Brussel et al. [7] proposed an expert system for scheduling flexible robotic assembly cells, which incorporates task scheduling levels and real time control levels. The system has the ability to create an ON-line scheduling by execution and monitoring of assembly sequence, from the beginning of the scheduling process to the last second they are completed. In 1996 Dell Valle and Camacho [8] proposed an expert system based approach for finding the best assembly planning and scheduling for a product in a multi-robot cell. The objective was the minimisation of assembly time. They specified feasible assembly plans by AND/OR graph representation.

2.3 *Simulation Approaches*

Simulation Approach (SA) is the imitation of the operations of various real-world facilities. Many of the research studies have been devoted to developing simulation tools for solving the problems of operations and manufacturing control, such as scheduling problems [9]. In the field of scheduling RFACs, Glibert et al. [10] used a software package called ROBCAD to simulate a robotic cell as a real assembly case. They presented ON-line and OFF-line approaches for scheduling multi-robot assembly cell. The objective was to reduce assembly time. In 1995 Hsu and Fu [11] developed a methodology to integrated scheduling with simulation in two steps. First, AND/OR graph approach have been proposed, to generated all feasible assembly sequences, and second, found an optimal sequence via applying a search algorithm. Another simulation approach was developed by Barral et al. [12] who considered simulation and experimentation to validate the framework. They introduced a flexible agent based framework for managing and operating multi-robotic assembly cells. The study decomposed an assembly operation into two separate stages: part fetching and part assembling.

2.4 *Summary of Related Studies*

Few studies have solved the scheduling problem of RFACs. Different approaches have been devoted to determine the reasonable scheduling policy. Most of these approaches are based on heuristics. In addition, there has been no previous study describing the scheduling RFAC for assembly of multi-products. The present study will attempt to describe a scheduling scheme of RFACs for concurrent assembly of multi-products.

Table 1: Literature survey on the centre scheduling of robotic assembly cell

No.	Author(s)	Type of work				Environment	
		Modeling	**Simulation**	**Optimisation**	**Multi Robot**	**Shop floor**	**Job Arrival**
1	Glibert et al.	√		√	√	Small cell	Static
2	Brussel et al.	√				Job shop	Dynamic
3	Nof & Drezner	√			√	Job shop	Static
4	Lin et al.	√			√	Single station	Static
5	Pelagagge et al.	√			√	Job shop	Static
6	Hsu & Fu	√	√	√	√	Job shop	Static
7	Dell Valle & Camacho	√	√		√	Job shop	Static
8	Jiang et al.	√			√	Single station	Static
9	Basran et al.	√		√		Small cell	Dynamic
10	Jiang et al.	√			√	Single station	Static
11	Marian et al.	√			√	Job shop	Static

3 Description of RFAC

In this section an example of RFAC in mechanical industry is described. We consider a multi-robot assembly cell from Marian, Kargas et al [1], as shown in Figure 1. The multi robot assembly cell is composed of a two robots (R1 and R2) that can use a number of tools that can be changed in a tool magazine (S5), assembly stations (S1, S3, S6, S7 & S9) where components are assembled, tables (S4, S2 & S8) to deposit the work in progress (WIP). There are also two conveyors. The first one (IC) supplies components to the cell and the second one (OC) is for conveying out a final product when assembly processes are completed. RFAC can assemble a number of related products based on group technology rules when the resources of the cell deal with similar parts and assembly processes [13].

A product, to be assembled, enters the RFAC as a collection of components (parts and subassemblies) through IC. A single product or number of products can be assembled at a time. The partial assemblies are identified and routed to assembly stations (S1, S3, S6, S7 & S9) where assembly operations take place to (S4 & S8) while waiting for an assembly station to become free or to transfer table (S4) to be transferred from one robot to another.

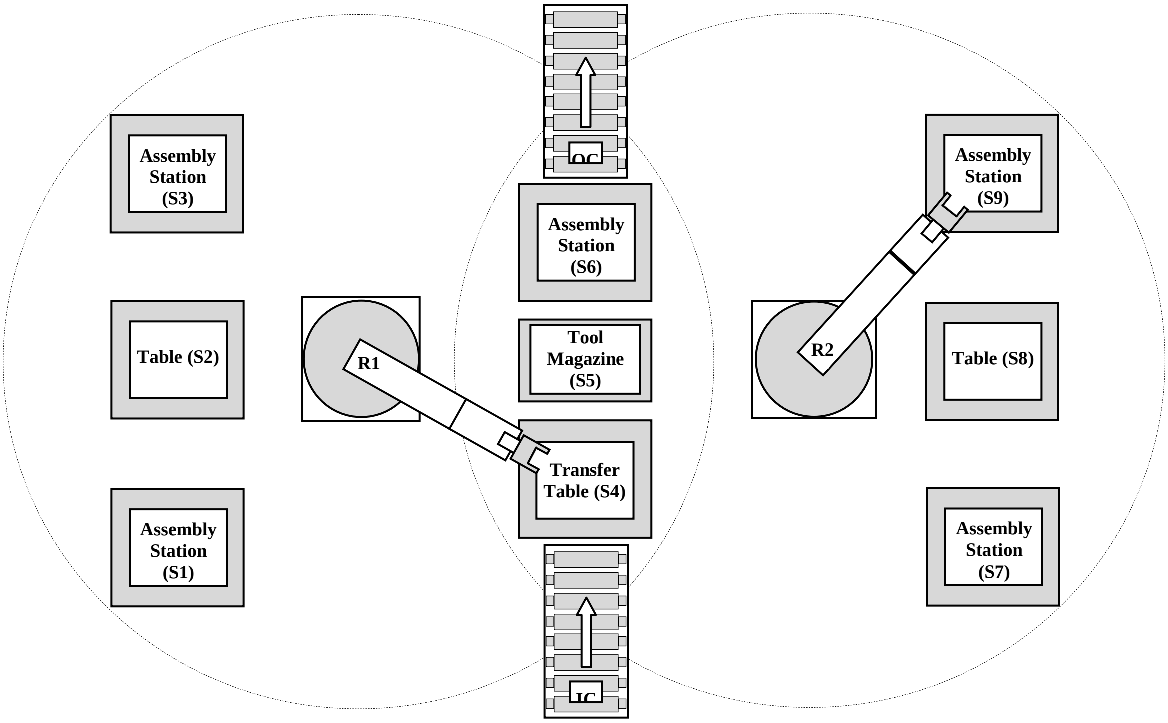

Figure 1: A Robotic Flexible Assembly Cell [1]

4 Suggested Framework

4.1 *Definition of RFAC Scheduling Problem*

The scheduling of the RFAC requires finding a way which determines how to use cell resources in an optimal manner to assemble multi-products. Let us consider an assembly cell in which a set of tasks are performed using a set of resources to assemble multi-products concurrently.

- Tasks represent any physical activities that are carried out by utilising resources. Task can be categorised into four types: move, tool-change, pick-up and assembly.
- Multi-products of the same family group usually involve similar operations; although, there are some differences in the assembly operations and the operational sequences among these products.

4.1.1 Assumption

The scheduling RFAC is a complex problem. Therefore, some assumptions are made in this study:

1. The optimum assembly sequence of each product is given in advance.
2. Each product uses some or all of the cell resources.
3. Each robot can perform only one task at a time.
4. No interruptions like resources breakdown in cell.
5. The processing time of each task is deterministic and is known in advance.
6. The set-up times are not considered.

4.1.2 Constraints

To provide a reliable solution to practical cases, the following constraints have been taken into account.

1. To prevent collisions between robots at shared area, such as component transfer table (S4), tool magazine (S5), assembly station (S6) and conveyors: IN and OUT, R1 and R2 cannot access these areas concurrently. This is the robot access constraints.
2. Robot cannot move from one place to another directly. This can be achieved by assigning four control points in the cell: C1 and C2 to robot 1,

C3 and C4 to robot 2. For example, R1 cannot move from S5 to S6 directly. To move from S5 to S6, R1 should move via control point C2, these requirements are called robot move constraints, as shown in Figure 2.

3. To fetch and assemble, the hand of each robot should be equipped with a right tool; however, a specific tool may be not available for the two robots concurrently, due to the restricted number of available tools. These are tooling resource constraints.

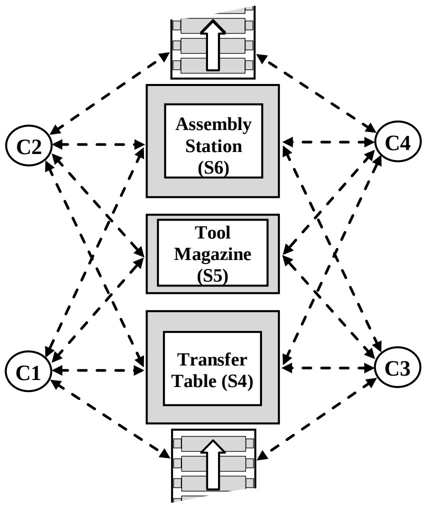

Figure 2: Robot move constraint

4.1.3 Objective function

Robots are a costly investment, it is vital to use them efficiently; hence the objective function of proposed methodology is to minimise the total time of assembly tasks to assemble multi products, consequently, maximising the output and increasing the utilisation of the cell.

4.2 *Methodology and System Structure*

The proposed methodology is characterised by the following three phases, as depicted in Figure 3.

4.2.1 Modelling Phase

The modelling phase is considered as a vital step in this methodology. It consists of three basic steps to define the model of RFAC.

1. Define the problem and the objective. The scheduling problem of RFAC involves how to use cell resources in an optimal ways, to assemble multi-products concurrently. The objective is to maximise the output of the assembly cell.
2. Collect data related to the technical characteristics of each product P_1 and P_2:
   - Components.
   - Optimum assembly sequence.
   - Processing time of each task.
   - Due date.

In addition, to model RFAC information is need for the cell resources such as assembly cell configuration and resources type.

3. Consider resource ***constraints,*** which are factors for scheduling RFAC. Section 4.1.2 describes these constraints in detail.

4.2.2 Scheduling Phase

Many studies have been devoted to developing simulation tools for solving the problems of operations and manufacturing control, such as scheduling problems [9]. Auto Mod is a highly flexible simulation tool that is used for analyzing complex manufacturing systems [14]. Simulation of RFAC can be totally build by Auto Mod, and be used to simulate all kinds of activities in the assembly cell which consists of:

1. Two robots: R1 and R2
2. Assembly stations: S1, S3, S6, S7 & S9
3. Tool magazine: S5
4. Tables: S4, S2 & S8
5. Conveyors: IN and OUT.

In scheduling a RFAC, the highest priority task is selected when a robot becomes free; this can be achieved using dispatching rules. These rules are commonly used for solving scheduling problems [14]. In this study, different dispatching rules will be used to evaluate RFAC performance on the basis of which a suitable schedule for the cell will be proposed. Some of the popular rules are [15]:

Rule1: SPT (Shortest Processing Times): select the jobs with minimum processing time first.

Rule2: RAND: random selection of items for processing.

Rule3: TWKR (Total Work Remaining): select a job with smallest total processing time for unfinished operations.

Rule4: LF (Latest Finish Time): give highest priority for an operation of the job that has the earliest completion time.

Rule5: FIFO (First In First Out): select a job that arrives first to the machine queue.

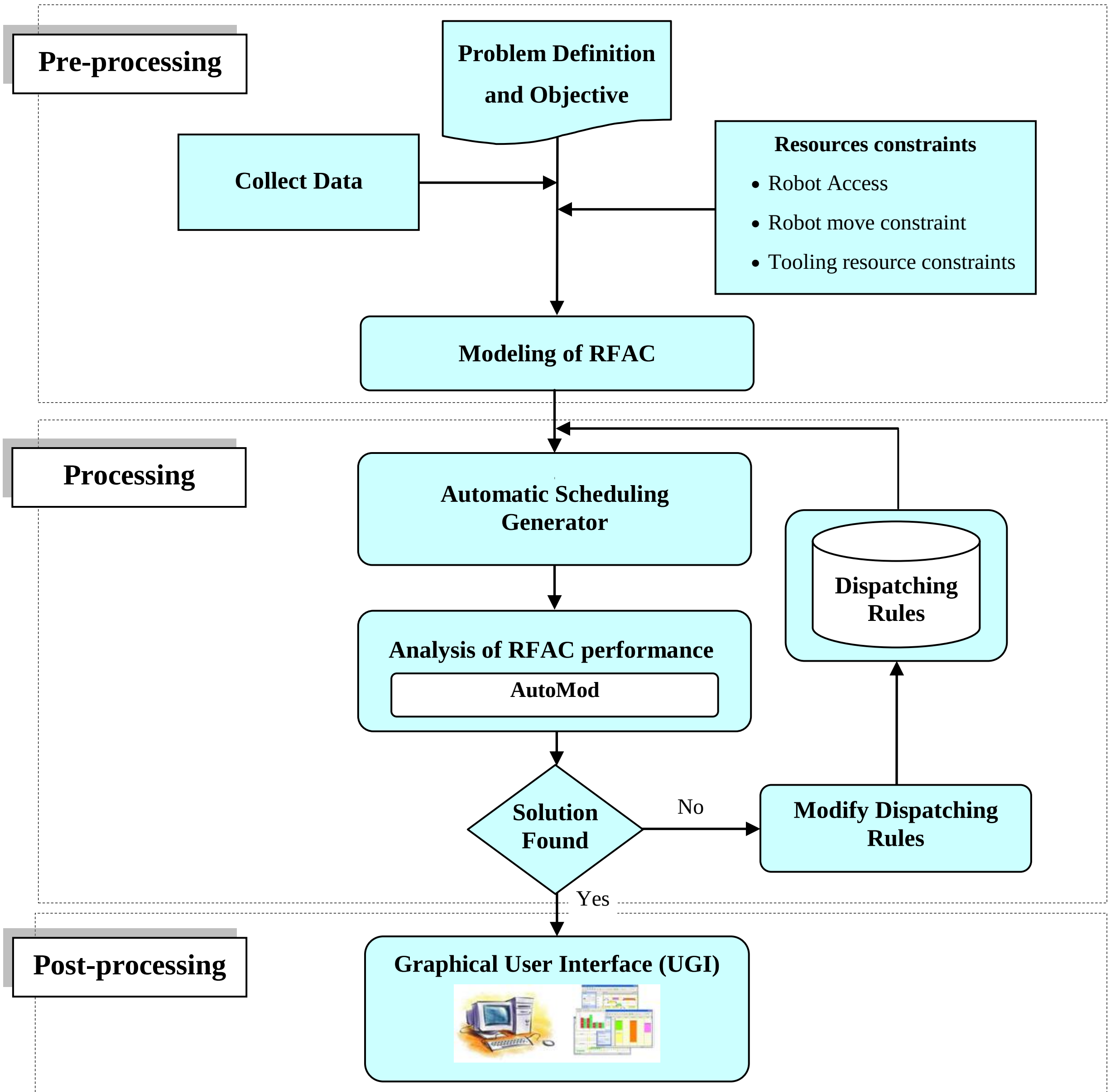

Figure 3: Schematic of proposed methodology

The scenario of simulation model of the cell consider two products P_1 and P_2, assembled simultaneously in the cell, with the corresponding $t_1P_1, t_2P_1 \ldots t_iP_1$ for P_1 and $t_1P_2, t_2P_2 \ldots t_iP_2$ for P_2.

Step1: Assign resources to carry out t_iP_1, based on Rule 1.

Step2: IF before completion of t_iP_1 resources that can be used to perform t_iP_2 are free, THEN assign those resources to carry out t_iP_2, ELSE wait until t_iP_1 is completed.

Step3: REPEAT Step 1 and Step 2 for remaining operations for P_1 and P_2 UNTIL product P_1 is completed.

Step4: REPEAT Step1 to Step 3 UNTIL product P_2 is completed.

Step5: Evaluate the performance of RFAC, identify the cell bottleneck and equipment utilisation.

Step6: IF the scheduling results is not acceptable, THEN REPEAT step1 based on Rule 2, ELSE presentation the result.

4.2.3 Analysis Phase

In the third phase, various analyses can be performed, where the simulation results are analysed with the aid of visualization software packages. The main goal of the phase is to present scheduling policy of RFAC. Gantt chart is an effective tool to deal with scheduling issues.

5 Conclusions

This paper describes a scheduling scheme of $RFAC_s$ for concurrent assembly of multi-products. The proposed methodology is based on dispatching rules. In addition, AutoMod is used as discrete events simulation software to evaluate the cell performance under different dispatching rules. The scheme focuses on the static scheduling problem without considering the dynamic nature of the market demands. The research will explore the dynamic scheduling of $RFAC_s$ to assemble multi-products.

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