ISSN : 0974 - 7435 Volume 10 Issue 23

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(23), 2014 [14186-14192]

Manufacturing execution system deadlock-free scheduling based on genetic algorithm and deadlock control policy

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ABSTRACT

This paper proposed a deadlock-free scheduling algorithm in manufacturing execution system based on Petri-net. It embedded deadlock avoidance policy into genetic algorithm in the method. By using the improved adaptive genetic algorithm and one-step-ahead optimal deadlock control policy, Deadlock free scheduling in Manufacturing execution system is solved. It optimized the quality of scheduling result, shorted the minimum make span and response time.

KEYWORDS

Petri-net; MES; Deadlock avoidance policy; Scheduling; Adaptive genetic algorithm.

INTRODUCTION

Manufacturing execution system is the executive layer which is between the operation control system SFC of the planning layer and workshop layer. It enhances the competitiveness of manufacturing by controlling materials, equipment, personnel, processes, instructions and all factory resources, so as to realize enterprises' real-time ERP/MES/SFC system. If a system is lack of effective scheduling and control strategy, it is easy taking place system deadlock when multiple processes are competing the limited resources[1]. At present, the shop scheduling algorithm is not only a hotspot which experts and scholars on domestic and foreign are researching, but also a difficulty. A lot of mature algorithms have been proposed so far, and intelligent optimization algorithm is such an example. Integrating the intelligent optimization algorithm into the shop scheduling system is an important trend in job scheduling.

MANUFACTURIG EXECUTION SYSTEM DEADLOCK-FREE SCHEDULING

The description of manufacturing execution system deadlock-free scheduling

In the manufacturing execution system, from a control point of view to solve the deadlock problem has been well studied development, many deadlock control strategies have been proposed, these deadlock control strategies to ensure no deadlock manufacturing execution system operation, but without considering the operating time, the performance of manufacturing execution system is not guaranteed[2]. The integrated scheduling problem using deadlock to manufacturing execution systems, manufacturing execution systems research deadlock-free scheduling problems, scheduling optimization system quality, is still an open field. Therefore, this paper proposes an effective control and scheduling algorithms to optimize system performance, to prevent the system to enter a deadlock state[3].

Manufacturing execution system deadlock control policy

This article uses the P-timed Petri net to create model, no deadlock genetic scheduling policy combining deadlock avoidance strategy is used to genetic algorithms, the minimum complete time and response time are taken into account by the scale optimization of the system[4]. In the manufacturing execution system, the feasibility of PN models with detection of chromosomal or scheduling scheme is NP-hard problem. This paper presents single step forward method to detect and repair feasible chromosomes, optimization deadlock control strategy based on polynomial complexity will not feasible to increase the feasibility of chromosomes by patching[5]. Since the detection and repair of chromosomes is a polynomial, so it does not increase the computational complexity of the basic genetic algorithm.

PETRI NET MODEL OF MANUFACTURIG EXECUTION SYSTEM SCHEDULING

The definition of petri nets

A Petri net is a quad $N=\left(P,T,F,M_0\right)$, where P is a finite set of places, T is a finite set of transitions, $F\subseteq(P\times T)\bigcup(T\times P)$ is a set of arcs, M_0 is the initial marking of N. There is a node $x\in P\bigcup T$ which denoted as:

$$\begin{aligned} {}^{\bullet}x &= \left\{y\in P\bigcup T \,\middle|\, (y,x)\in F\right\} \\ x^{\bullet} &= \left\{y\in P\bigcup T \,\middle|\, (y,x)\in F\right\} \end{aligned} \tag{1}$$

The establishment of petri-net model

This paper considers the manufacturing execution system composed by m resources, the set of resources is denoted as $R=\left\{r_i, i=1,2,\cdots,m\right\}$. Assuming the work piece handing capacity of resource r_i is $\Psi\left(r_i\right)$. The system can handle n kinds of different types of work piece, the set of work piece types is $J=\left\{J_1,J_2,\cdots,J_n\right\}$. Assuming the number of J_i type work piece to be machined is y_i. Processing resources and time required for the operation is determined in advance, with the same kind of work piece machining path. Assuming machining path of J_i type work piece u use its sequence of operations $O_{i1u}O_{i2u}\cdots O_{iL(i)u}, u=1,2,\cdots,y\left(i\right)$, where, $L\left(i\right)$ is operand processing required for the J_i type work piece.

Genetic algorithms

Genetic algorithms are research and optimization methods based on biological evolution mechanism. As used here, the improved adaptive genetic algorithm generates an initial population of chromosomes firstly, and each chromosome represents a feasible solution and accepts a fitness value, representing solve quality of problems[6]. Typically, a lot of viable chromosomes are selected to the next generation, only a few chromosomes are discarded. The chromosomes that are selected must be superior to other chromosomes and have a higher fitness value, but they do not affect the genetic differences between populations. After the selecting operation, some chromosomes produce the next generation through modifying crossover and mutation. Determining whether to accept the select operation is by chromosomes feasibility which is based on chromosomal mutation rate and crossover rate. This process will not end until you find a satisfactory solution or the termination conditions are met[7].

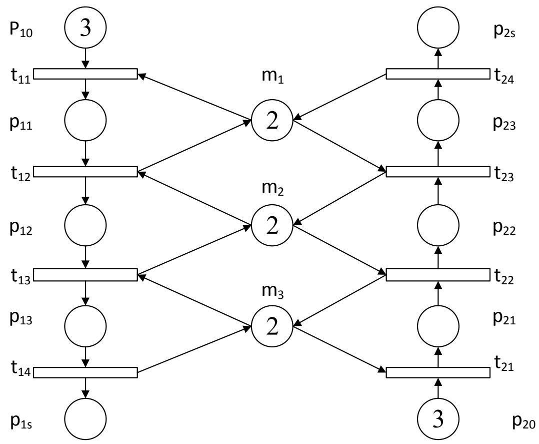

Figure 1 : Petri net model of manufacturing execution system

DESIGN OF MES ON DEADLOCK SCHEDULING ALOGRITHM

The algorithm adjusts the crossover rate and mutation rate adaptively according the performance of genetic manipulation, so as to solve the balance between space exploration and development.

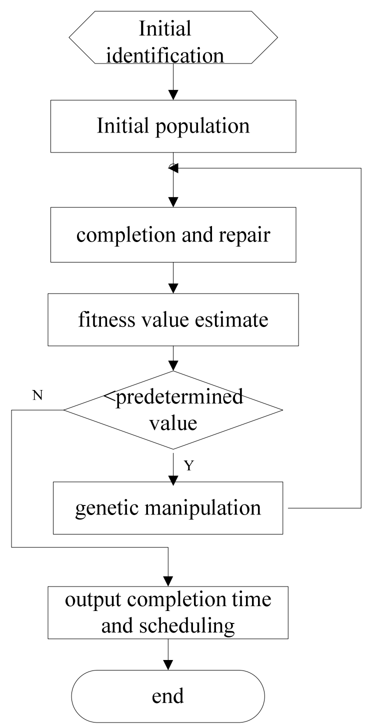

Figure 2 : Manufacturing execution system deadlock-free scheduling scheme

Genetic algorithms are described below:
Definition of S (t) of the t -generation chromosome population
t ← 0
Initialization S (t)
Rate S (t)
The termination condition is not satisfied
t ← t +1
Choose S (t) to S (t +1)
Cross S (t)
Mutant S (t)
Rate S (t)
End

The objective function

The objective function can be used to guide the achievement of the genetic algorithm, and is expected to get optimal results, such as a maximum or minimum of the function. In this article, the minimum completion time means that the process leaves the system in the completion time of the last part[8]. The objective function is used to construct the fitness function of chromosomes.

Encoding, decoding, perfection and modifications

Encoding and decoding

In the methods using in this paper, the work-piece to be machined all numbered $q, q = 1, 2, ..., \sum y(i)$ at first. The coding of a solutions is a sequence number of the work-piece and the number of times a *Ji* work-pieces numbered q appears is the number of steps $L(i)$ required for process and work in manufacturing execution system. The k-th occurrence represents the k-th step of the work piece. $\pi = (2,5,3,6,2,1,5,2,3,3,4,1,5,4,4,6,6,1)$ is a possible coding, in which 1, 2, 3 represents three different parts of Class 1, and 4,5,6 represents of three different parts of Class 2. With a figure $q(=1,2,...,6)$ appeared three times, it represents the first, second, third step of the work-piece respectively. Due to one relationship between the process and the changes on behalf of the beginning of the process in the Petri net model, such a coding also represents input changes sequence corresponding to the process position. According to the actual, this article assumes that the finished work piece can leave the system, $t_{i(L(i)+1)}$ can be raised.

Perfection and modifications

In the best of the controlled system Petri net model, the necessary and sufficient condition of the feasibility of a chromosome is that it's corresponding transition sequence is a viable trigger sequence of the controlled system Petri net model. If the genome sequence is not completed, it may cause a deadlock, and the transmission sequence is not a feasible sequence. In this article, the completed and repair methods of chromosomes appears individually, so it is feasible.

Firstly, the complete the genome sequence. Adding the change of the end of a work piece to the last operation, according to each portion of the work piece J_i which is in chromosomal sequences path W_i, $i \in \{1,2,...,n\}$, And the extension sequence of this change is added to the chromosomal sequences simply. For example: Some of the work piece J_1, J_2, J_3, J_4 increase end-changes $t_{15}, t_{15}, t_{34}, t_{34}$, and the genome sequence complete coding, i.e., by the following formula:

$$\begin{aligned}\partial(Chm1) = (&t_{11}, t_{12}, t_{31}, t_{11}, t_{22}, t_{31}, t_{23}, t_{32}, t_{33},\\ &t_{32}, t_{33}, t_{24}, t_{13}, t_{14}, t_{15}, t_{15}, t_{34}, t_{34})\end{aligned} \quad \textbf{(2)}$$

Modified algorithm is a recursive process. At each step, it selects a security enabled flag M as a change chromosomal sequence and updates the current fag M by triggering the selected changes in the change chromosomal sequence that are not selected. If the genome sequence does not contain such a change of flag M, the path of conflict will occur as is known. In a safe and reachable state or flag M, a transition t can be triggered at least. For the feasibility of the part of the path in the manufacturing execution systems, it may have more than one process path in the repair process of modifying chromosomal sequences. Choosing a path for each part in chromosomal sequences when chromosome defined as $Chm = (S_r; S_o)$.

Generate initial population

One chromosome which satisfied the conditions of encoding is randomly generated, and it becomes a viable chromosome by feasibility checking and repairing. Initial population is consisted of by chromosome like m which is randomly generated.

Fitness function & its calculation

Based on the scheduling objectives (make span) as the fitness function f as genetic algorithm. Given feasible chromosomes represented as: $\pi = (v_1, v_2, ..., v_n)$, the corresponding operation scheduling v1 represents began to execute them one by one.

$st_{ij}(k)$: it means the change of the first k lead time, also is the first k times (y) (I) times start processing time;

$pt_{ij}(k)$: Said change triggered the first k times tolkien should at least stay time in the position, the corresponding to the first k times need the processing time of operation.

$f(\pi) = \max st_{iL(i)}(y(i)) + pt_{iL(i)}(y(i)) \;\; i = 1, ..., n.$

Repeated permutation genetic manipulation

Genetic operations include selection, crossover and mutation.

Selection is to choose the excellent individuals from groups, and eliminate inferior individual operation. This article USES is the best individual preservation method, which select the optimal individual fitness in parent directly copied to the offspring[9].

Crossover is an important type of operation in genetic algorithm. Specific crossover operation is: the random selection of two parent chromosomes PA and PB, then randomly choose a crossing point A and B from them, choose an arbitrary integer as A crossover length, choose the right length of points A(B) from PA(PB) as A cross section for gene, cross segment on PA (PB) which be in the corresponding gene PB (PA) will be set to zero, advance the gene that is set to zero, replace it with corresponding PB (PA) gene segments, thereby generating a CA (CB)[10]. Variation makes individuals in the population to be mutated to produce a new gene, in order to prevent premature phenomenon, and search better results. This article take the mutation operation is: randomly select a parent chromosome, and randomly generated two positions in this chromosome, and then invert the new chromosomes that produced by new genes between two places. Chromosome that generated by the crossover and mutation above must satisfy the machining process, but not necessarily meet the resources and control the constraints. So it needs reality check and repair operations, thus ensuring that offspring produced through evolutionary operation are feasible chromosomes.

EXEPERIMENT AND ANALYSIS

The traditional job shop and flow shop scheduling have m × n scale, it means m machines, n processes. Assuming manufacturing execution system has enough buffer or human resources, and the system there is no deadlock. If neither buffer nor the human resources or only given a certain amount of buffer tank, then no deadlock scheduling system will not be guaranteed. In the manufacturing execution system, first consider there is sufficient buffer space, optimal scheduling by genetic algorithm, so this scheduling will lead to deadlock. In a deadlock condition, should increase the number of buffers. In this paper, in order to obtain optimal or optimum manufacturing execution system deadlock-free scheduling program that will optimized the time complexity of polynomial DAP combined with adaptive genetic algorithm, repeating parts or all parts of the genetic sequence of operations and the completion of the operation / repair algorithm based on chromosome replacement. This proposed scheduling magnified given set of resources can be applied to manufacturing execution systems. It uses the improved benchmark problem to do experiments, and use single step forward deadlock avoidance strategy.

Assuming the 3 work piece of first class are numbered 1, 2, 3, and the second are numbered 4, 5, 6. Processing machines and processing time information table are given in TABLE 1.

TABLE 1 : Work piece information

1	2	3	4	5	6
m1:40	m1:45	m1:53	m3:35	m3:62	m3:73
m2:55	m2:10	m2:24	m2:21	m2:31	m2:56
m3:50	m3:20	m1:25	m1:33	m1:35	m1:44

The adaptive genetic algorithm is used 50 times to get the results shown in TABLE 2. Where pc is the crossover probability, pm is the mutation probability, genetic algebra is 100. With Ma-ms, Mi-ms and Av-ms represent the worst result, best results and the average results obtained in the 50 calculation, Mtime represents a running average time(s).

TABLE 2 : Scheduling result

	Ma-ms	Mi-ms	Av-ms	Mtime
pc=0.8, pm=0.05	201	194	197.0	1.592
pc=0.8, pm=0.10	198	193	196.0	1.603
pc=0.8, pm=0.15	201	193	196.2	1.614

The results can be seen in TABLE 2, the crossover probability pc = 0.80, mutation probability pm = 0.10, the result of the scheduling is relatively good.

To compare the results of genetic algorithm (GA) and adaptive genetic algorithm (AGA) in TABLE 3, determine the completion time for the time unit, execution time is in ms.

Simulation results AGA and GA algorithms are shown in Figure 3. results of AGA algorithm has proposed in this paper increased 62%, to compare the results of 20 experiments, running time of AGA algorithm is much more than GA algorithm, the result is better than GA algorithm, and the algorithm can be realized 90%.

TABLE 3 : Comparison of algorithm results

AGA			AG	
Time # Makespan (ms)			**Time # Makespan (ms)**	
1	5008	20625	4501	9650
2	5125	20463	5175	9356
3	4763	20756	4996	9369
4	5039	20936	5123	9295
5	4589	20567	4981	9386
6	5088	20769	5201	9419
7	5039	20836	5001	9589
8	5059	21903	5087	9108
9	5429	23116	5002	9435
10	5049	22175	5043	9563
11	4692	22235	5359	9216
12	5049	23329	5077	9586
13	5026	24436	4586	9168
14	5032	23701	5059	9403
15	4916	23341	5039	9423
16	5061	22716	5097	9327
17	5062	22718	4975	9733
18	4748	22734	5030	9577
19	4615	21702	5098	9421
20	5098	22155	5043	9515

The average execution time of GA algorithm presented by this paper is 21.746s, while the average execution time of GA is 9.345s, which indicates that the proposed algorithm AGA within the maximum time required for the completion of the execution time is less for larger work piece and machine manufacturing systems to achieve optimized production scheduling, scheduling deadlock-free manufacturing execution system in the shortest possible execution time and improve productivity.

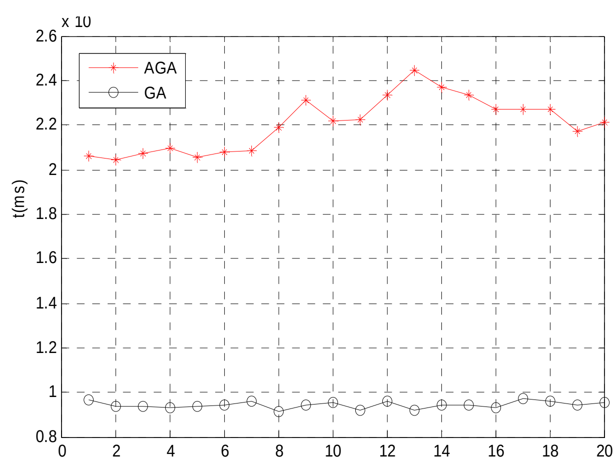

Figure 3 : Algorithm simulation results

CONCLUSIONS

This paper studies the manufacturing execution system deadlock-free scheduling problem, the same path for the same kind of multi-species work piece batch processing system, there will be no deadlock control strategy combines the adaptive genetic algorithm, proposed a new genetic scheduling algorithm Dead-lock. Algorithm is repeated part of the chromosome substitution approach, Petri nets model, a single step forward by patching strategies, testing and repair of chromosomal genetic manipulation to produce it to meet the corresponding resource constraints and scheduling deadlock-free requirements.

From a theoretical point of view, the proposed method is applicable to the manufacturing execution system under various conditions. However, given the complexity of the control strategy, this method is more suitable for a greater number of kinds of the number of processes and manufacturing execution systems. By adapting the type of genetic manipulation, genetic scheduling algorithm has been improved. Because all of the adaptive genetic algorithm can be repaired and chromosome encoded as feasible schedule, so the result is largely improved the scheduling algorithm. However, for improving the performance and computational complexity of the optimization controller deadlock needs further study.

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