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Flower Pollination Algorithm for Scheduling Optimization of Flexible Manufacturing System

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Abstract:

Flexible manufacturing system (FMS) is a part of smart manufacturing and their implementation is on the rise in manufacturing industrial scenario. The need of FMS arises in order to meet the customized demands of consumers. It is highly complicated due to its flexibility, tools and AGVs which makes it unpredictable dynamic manufacturing environment. Finding an optimal schedule is relatively easy for small instance problems, whereas large realistic problems are difficult to solve. Recently, many swarm intelligence techniques have been developed and implemented to achieve an optimal schedule for FMS. Flower Pollination Algorithm (FPA) is one of the swarm intelligence techniques which mimics the behaviour of pollination of flowering plants. This paper proposes a Hybrid Flower Pollination Algorithm (HFPA) which is an amalgamation of classic FPA with Simulated Annealing (SA) to solve two objectives-1) to minimise the machine idle time and 2) to minimise the total penalty cost. The algorithm's efficiency is demonstrated through comparison of HFPA with other meta heuristics found in literature and it is concluded that HFPA gives better results in less computational time.

Keywords — ***Flexible manufacturing system, Hybrid Flower Pollination algorithm, scheduling, multi-objective.***

1. Introduction

Flexibility is a major consideration in the design of manufacturing systems. Flexible manufacturing systems (FMSs) have been developed over the last two decades to help manufacturing industry move towards the goal of flexibility. An FMS comprises three principal elements: computer controlled machine tools; an automated transport system and a computer control system. An FMS combines high levels of flexibility with high productivity and low levels of work-in-process inventory. It may also allow unsupervised production. In order to achieve these desirable benefits the control system must be capable of exercising intelligent supervisory management. Scheduling is at the heart of the control system of an FMS. The development of effective and efficient FMS scheduling strategies remains an important and active research area. Scheduling problems of FMS are known to be NP-hard, which means that they are intractable and the computation time increases exponentially as the problem size goes up. Some assumptions have been made about scheduling problems in order to simplify the model and solve it. One of these assumptions is that the transferring times of jobs between different machines are negligible.

However, it is highly impractical not to model the material handling activities in scheduling problems in reality, especially when the movements of jobs are completely relying on the material handling equipment and their transferring times are comparable to the production times. Omission of transferring times will make the result of scheduling impossible for implementation.

1.1 Earlier Research

The optimization of scheduling are usually done by different approaches spanning from mathematical approaches and branch and bound techniques to bottleneck based heuristics, artificial intelligence and by local search methods. This section of literature helped the research scholar in exploring the FMS and to understand the need for better scheduling. The summary of literature surveyed in this regard is given below.

Liu et al [1] gave a detailed review on FMS, its variations, its components, scheduling problems and different methodologies used to solve for FMS. The study made by Sharma [2] helps the practitioners to study about various issues encountered in FMS setup and it also helps in bridging the gaps between the various crucial aspects required for its implementation.

Wu et al [3] addressed a single-machine total completion time problem with learning effect and release times based on the sum of processing times. A simulated-annealing algorithm was also proposed to obtain a near optimal solution. They proposed for Future research may consider other criterion such as the tardiness or lateness or studying the problem in the multi-machine setting. Noorul Haq et al. [4] employed a Giffler and Thompson heuristic with six priority-dispatching rules for determining the best routing of the jobs and this optimum part routing is considered as an input to schedule the material handling system. In order to minimize the distance travelled by the AGV and transportation cost of the AGV, a hybrid approach of GA and simulated annealing is employed for obtaining quality solution. Jerald et al [5] implemented optimization approaches such as GA, SA, Mematic algorithm and PSOA for a multi objective function. The results show that PSOA is found to be better than other three algorithms and provides the minimum combined objective function value. Chawla et al. [6] evaluated the performance of dynamic job selection dispatching rules for simultaneous dispatching and scheduling of multi-load automated guided vehicles (AGVs) cruising in two different sizes of FMS. Zhao et al [7] proposed genetic algorithm (GA) to solve the job-sequencing problem for a production shop that is characterized by flexible routing and flexible machines. Saravanan [8] proposed a modified NSGA II to solve FMS scheduling and he demonstrated that his method is very effective. Pandey et al [9] presents a review on design and control of automated guided vehicle systems. Various types of scheduling problems are solved in different job shop environments, vehicle routing, guide-path design, vehicle dispatching. The prior objective of this paper is to extend previous research by examining the effects of scheduling rules and routing flexibility on the performance of a constrained and utilization of AGVs and machines. Prakash Babu et al [10] made an attempt to study the machine and vehicle planning features simultaneously in an FMS for minimization of the make-span.

Swarm intelligence techniques are gaining importance recently to solve large real life manufacturing problems. After a detailed study of literature, we aim to solve the FMS scheduling problem by Hybrid Flower pollination algorithm. The study made by Abdel-Baset and Hezam [11] provides a detailed working methodology of Flower pollination Algorithm (FPA) . The paper also discusses about various hybridizations used for FPA so far. Khursheed et al. [12] is another review article that details about the variations prosed for FPA and its applications. This article also serves as good base paper. [13] solved a scheduling problem by disparity count process with FPA. [14] solved flexible job shop problem (FJSP) by

FPA which includes fuzzy processing time. Sivarami Reddy et al [15] solved the simultaneous scheduling of machines and AGVs using FPA. And demonstrated the efficiency of the proposed algorithm. Therefore after a thorough analysis of recent literature from last decade, this paper aims to solve a FMS scheduling problem for 80 jobs and 16 machines with multi objectives of minimizing the machine idle time and minimizing the total penalty cost. The results have been compared with other known metaheuristics and conclusions are drawn.

2. Problem Description

The problem environment, assumption and aim of the present work are as follows:

1. The FMS considered in this work has a configuration as shown in Fig. 1. There are five flexible machining cells (FMCs), each with two to six computer numerical machines (CNCs), an independent and a self-sufficient tool magazine, one automatic tool changer (ATC) and one automatic pallet changer (APC). Each cell is supported by one to three dedicated robots for intra-cell movement of materials between operations. There is a loading station from which parts are released in batches for manufacturing in the FMS. There is an unloading station where the finished parts are collected and conveyed to the finished storage. There is one automatic storage and retrieval system (AS/RS) to store the work in progress. The five FMCs are connected by two identical automated guided vehicles (AGVs). These AGVs perform the inter cell movements between the FMCs, the movement of finished product from any of the FMCs to the unloading station and the movement of semi-finished products between the AS/RS and the FMCs.

2. The assumptions made in this work are as follows: There are 40 to 80 varieties of products for a particular combination of tools in the tool magazines. Each type/variety has a particular processing sequence batch size, deadline and penalty cost for not meeting the deadline. Each processing step has a processing time with a specific machine. The problem matrix taken is given in table 1.

3. The objective of the schedule is the combination of minimizing the machine idle time and minimizing the total penalty cost.

$$COF = (w1)^{*}\frac{\textit{Total penalty cost}}{\text{Maximum permissible penalty}} + (w2)^{*}\frac{\text{Total machine idle time}}{\text{Maximum total machine elapsed time}} \qquad (1)$$

Where w1and w2 are the weights assigned to each objective function.

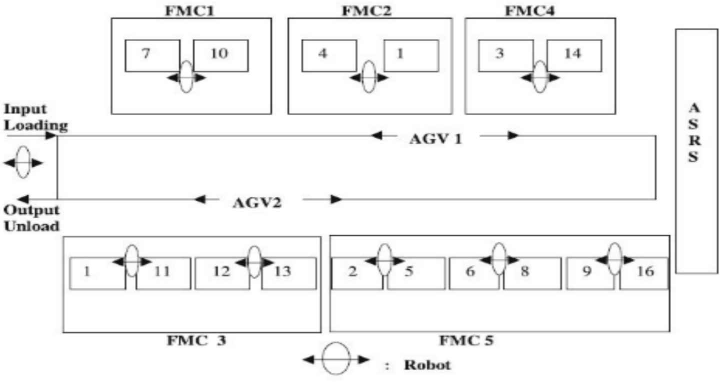


Fig 1. FMS Structure

3. Proposed Methodology

3.1 Classic FPA

Flower pollination is a process related to transferring flowers' pollens. Transferring flowers' pollens are carried by birds, bats, insects and other animals. There are two categories of pollination i.e., abiotic and biotic. In biotic pollination, pollinators transfer pollen and abiotic pollination does not require pollinators. Some pollinators tend to visit some specific type of flowers and at the same time, other species of flowers will be bypassed. This phenomenon is known as flower constancy. All the flowers with flower constancy property guarantee the reproduction maximisation.

Pollination can be achieved through cross- pollination or self-pollination. In cross-pollination, pollens are transferred from a different plant (Yang, 2012).

The cross pollination takes place at long distances and is usually carried by pollinators like bats, bees, butterflies and they are considered as discrete jumps that obey Levi distribution.

The following rules idealizes the FPA

- biotic and cross-pollination is interpreted as global pollination where the pollinators carrying pollens performs levy flights
- the abiotic and self-pollination can be recognized as local pollination
- flower constancy can be considered as a reproduction capability and is proportional to the similarity of the two flowers involved
- due to the wind and physical proximity, local pollination has a little advantage over global pollination.

Rule 1 can be mathematically represented as shown in Eq 2

$$X_i^{t+1} = X_i^t + L\,(X_i^t - \ g\,*) \qquad (2)$$

where X_i^t is the individual flower at generation t, L denotes step size from the levy distribution, and g* is the best solution of all.

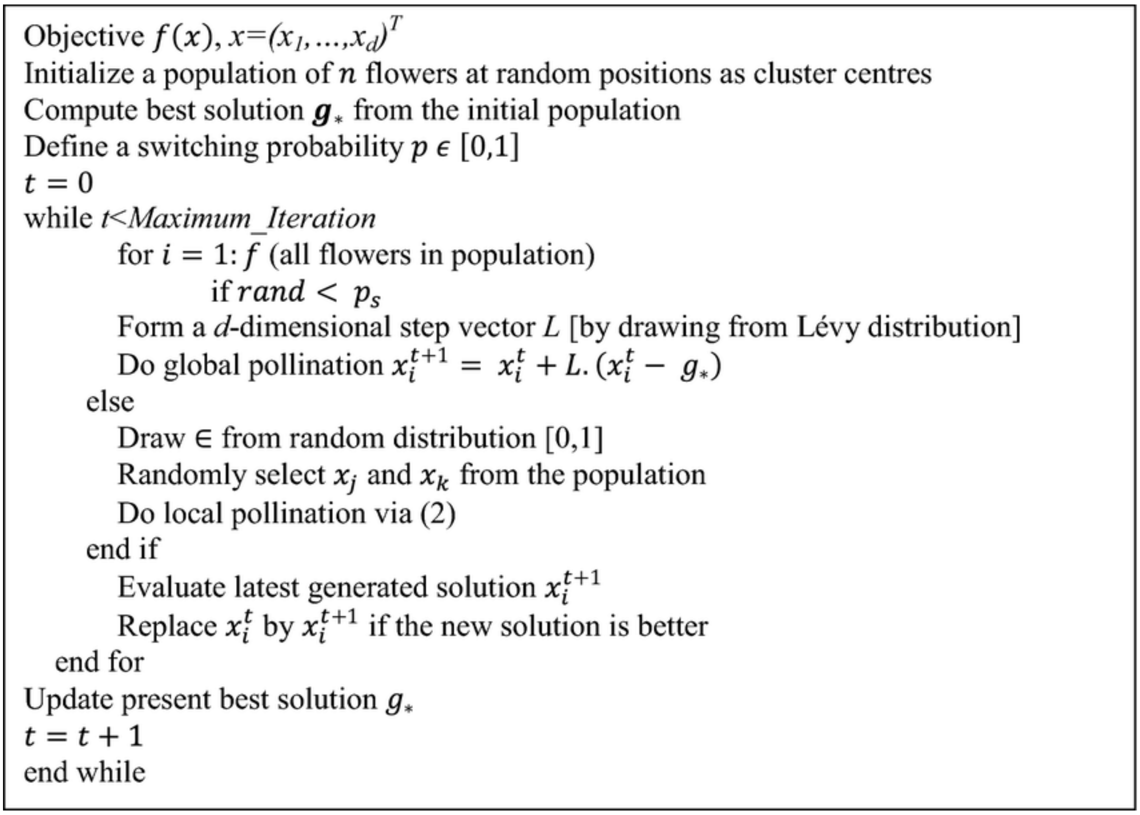
Rule 2 and 3 can be represented as shown in Eq 3

$$X_i^{t+1} = X + U\,(X_j^t - X_k^t) \qquad (3)$$

Where X_j^t and X_k^t are pollen from different flowers of the same plant species. This essentially imitates the flower constancy in a limited neighborhood. Mathematically, if X_j^t and X_k^t comes from the same species or selected from the same population, this equivalently becomes a local random walk if we draw U from a uniform distribution in [0, 1].

Switch probability p € [0, 1] controls local pollination and global pollination.

If a randomly generated number is less than Switch probability p, global pollination takes place otherwise local pollination takes place. From the literature study done, it is proven in various studies that p=0.8 provides a better solution. The pseudo code of classic FPA is shown in Fig 2.



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Objective $f(x)$, $x=(x_1,\ldots,x_d)^T$
Initialize a population of $n$ flowers at random positions as cluster centres
Compute best solution $\boldsymbol{g}_*$ from the initial population
Define a switching probability $p \in [0,1]$
$t = 0$
while $t$<Maximum_Iteration
      for $i = 1: f$ (all flowers in population)
            if $rand < p_s$
      Form a $d$-dimensional step vector $L$ [by drawing from Lévy distribution]
      Do global pollination $x_i^{t+1} = x_i^t + L.(x_i^t - g_*)$
    else
      Draw $\in$ from random distribution [0,1]
      Randomly select $x_j$ and $x_k$ from the population
      Do local pollination via (2)
    end if
      Evaluate latest generated solution $x_i^{t+1}$
      Replace $x_i^t$ by $x_i^{t+1}$ if the new solution is better
  end for
Update present best solution $g_*$
$t = t + 1$
end while
```

Fig 2 Pseudo code for classic FPA

3.2 Hybrid Flower Pollination Algorithm Methodology (HFPA)

In the proposed algorithm, we have incorporated Simulated Annealing with classic FPA to excel its performance and also to avoid local optima entrapment. The Simulated annealing (SA) is one of the simplest and most popular heuristic algorithms. SA is a global search algorithm, based on annealing process of metal processing. It has been proved that it can have global convergence, though the convergence rate can be very slow. It is based on Monte Carlo iterative solution strategy. Its main advantage is that it not only accepts better solution than the current state, but also it can jump out of local minimum.

3.2.1 Working of HFPA

The initial solution is randomly generated in the standard simulated annealing algorithm. Therefore, the size of the solution is uneven. This feature will affect the effectiveness of algorithm. The defect can be avoided by using flower pollination algorithm to create the initial solution. In order to enhance the searching efficiency, the new solution is generated by FP algorithm. The worst solution is replaced by the new solution. The advantage of the searching process lies in retaining the intermediate optimal solution and updating on time. Finally, annealing process is executed once again based on the final optimal solution. Since FPA works on continuous problems it has to be discretized before it is implemented for scheduling FMS. This paper adopted the discretization method proposed by [14].

The parameters used in this study are; i) the population size (number of flowers) = 50, ii) selection probability of pollination method p =0.8, and iii) maximum iterations = 5000

4. Results and Discussions

The FMS configuration considered in this work is taken from existing literature [16]. The proposed algorithm has been implemented for 80 jobs for 16 machines using combined objective optimization method. The problem matrix taken for this study can be found in [16]. In the experiments conducted, we have done simulations for different weights. (i) Simulation 1: w1 = 0.5 w2 = 0.5 (ii) Simulation 2: w1= 0.6 w2= 0.4 (iii) Simulation 3: w1= 0.4 w2= 0.6. HFPA has been run for different weights in the COF formula and the results are tabulated in Table 1. The optimal solution found by varying weights are highlighted in bold letters. Matlab software version R2016b and above is used for programming the proposed approach. The use of matlab enables us to solve complex scheduling problems involving different job types and multiple machines. TOMLAB/CPLEX has also been used in our program as it's a subproblem solver and handles quicker solving of mixed-integer linear and quadratic programming (MILP,MIQP), and linear and quadratic programming (LP,QP). Different optimal schedules are obtained for the FMS using the above hybrid approach, and the performances are compared and analysed. A comparison between the proposed HFPA and other algorithms, namely GA [5], SA [16] , Memetic Algorithm, GAPSOTS [17] (found in literature) have been shown in Table 2. The proposed algorithm has been run for different iterations. When the iterations number are less the results were not good, but as iterations increased, we got better results. We stopped at 5000 iterations as there was no significant change in optimal value later.

Table 1: COF for different weights

PROBLEM	W1 0.5, W2 0.5	W1 0.6 W2 0.4	W1 0.4, W2 0.6
80 J X 16 M	**0.075676**	0.08132	0.12037

Table 2 Comparison of results for various techniques with GAPSOTS

Problem Size	Objectives	Genetic Algorithm	Simulated Annealing	Memetic Algorithm	GAPSOTS	HFPA
80 jobs x 16 machines	COF	0.0959237	0.14738715	0.1067266	0.08537	0.075676
	Sequence	34,50,59,76, 48,69,31,11, 1,26,56,23,4 7,25,62,20,3, 78,55,53,24, 51,70,71,75, 46,58,74,4,2, 28,18,38,22, 54,5,72,12,1 3,40,10,60,6 5,79,43,37,6 6,27,42,7,64, 61,29,35,36, 73,39,49,67, 2,41,15,17,4 4,45,63,21,6, 80,9,19,57,1 4,33,16,68,5 2,77 ,8,32	41,53,51,70,1,7 1,47,58,36,61,3 0,4,23,54,75,77, 76,52,79,31,15, 78,35,59,66,72, 55,56,64,28,40, 13,45,17,14,48, 80,49,34,25,10, 20,44,29,11,60, 67,38,27,9,12,3 2,46,5,18,43,65, 37,24,21,42,2,6 3,19,7,22,33,74, 26,57,16,62,3,3 9,69,6,50,73,68, 8	69,17,36,2 4,74,61,20, 35,75,49,2 5,18,58,47, 3,52,28,45, 51,59,46,6, 16,34,31,5 3,70,76,22, 2,40,79,15, 30,62,54,3 8,10,43,13, 80,37,71,2 6,66,73,72, 65,56,67,1 2,1,4,5,21, 32,77,27,2 9,63,33,60, 64,57,41,9, 14,48,55,7 8,7,42,11,2 3,39,8,50,6	39,26,8,32, 35, 78,59,27,51, 18,19,31 52,71,57 5,1,74,22 13,63,58 33,34,65 29,48,42,70, 17,9,56,40,4 9,67,30, 3,66,7,45,11, 23,80,38,16, 46,44,21,60, 75,24,10,4,5 3,47,15,76,2 0,6,54,72,43 64,50,2,14,7 3,25,69,77,4 1,28,79,61,5 5,68,36,12,3	35,75,49, 69,17,36,24, 74,61,20, 25,18,58,47, 52,28,45,51, 59,46,6, 16,34,31,53, 70,76,22,2,4 0,79,15, 30,62,54,38, 10,43,13,80, 37,71,26,66, 73,72,65,56, 67,12,1,4,5,2 1,32,77,27,2 9,63,33,60,6 4,57,41,9,14, 48,55,78,7,4 2,11,23,39,8, 50,68 ,19,44

				8 ,19,44	7,62	

5. Conclusions

Optimization procedure has been developed in this work which is based on genetic algorithm and is implemented successfully for solving the scheduling optimization problem of FMS. Software has been written in Matlab. Results are obtained for the 80 jobs and 16 machines FMS system. With less computational effort it is possible to obtain the solution for such a large number of jobs (80) and machines (16).This work leads to the conclusion that the procedures developed in this work can be suitably modified to any kind of FMS with a large number of components and machines subject to multi objective functions. Future work will include availability and handling times of loading/unloading stations, AGVs.

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