ASSEMBLY SEQUENCE PLANNING USING HYBRID BINARY PARTICLE SWARM OPTIMIZATION

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Dedicated, in thankful appreciation to my father, who loved me and did not only raise and nurture me but also taxed himself dearly over the years for my education and intellectual development.

Dedicated to my mother, who has been a source of endless love, motivation and strength during moments of despair and discouragement.

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ABSTRACT

Assembly Sequence Planning (ASP) is known as a large-scale, time-consuming combinatorial problem. Therefore time is the main factor in production planning. Recently, ASP in production planning had been studied widely especially to minimize the time and consequently reduce the cost. The first objective of this research is to formulate and analyse a mathematical model of the ASP problem. The second objective is to minimize the time of the ASP problem and hence reduce the product cost. A case study of a product consists of 19 components have been used in this research, and the fitness function of the problem had been calculated using Binary Particle Swarm Optimization (BPSO), and hybrid algorithm of BPSO and Differential Evolution (DE). The novel algorithm of BPSODE has been assessed with performance-evaluated criteria (performance measure). The algorithm has been validated using 8 comprehensive benchmark problems from the literature. The results show that the BPSO algorithm has an improved performance and can reduce further the time of assembly of the 19 parts of the ASP compared to the Simulated Annealing and Genetic Algorithm. The novel hybrid BPSODE algorithm shows a superior performance when assessed via performance-evaluated criteria compared to BPSO. The BPSODE algorithm also demonstrated a good generation of the recorded optimal value for the 8 standard benchmark problems.

ABSTRAK

Perancangan Jujukan Pemasangan (ASP) dikenali sebagai masalah kombinatorik berskala besar yang memakan masa. Oleh itu masa adalah faktor utama dalam perancangan pengeluaran. Baru-baru ini, ASP dalam perancangan pengeluaran telah dikaji secara meluas terutamanya untuk meminimumkan masa dan seterusnya mengurangkan kos. Objektif pertama penyelidikan ini ialah merumus and menganalisa model matematik bagi masalah ASP. Objektif kedua ialah untuk meminimumkan masa bagi masalah ASP dan seterusnya mengurangkan kos produk. Satu kajian kes bagi satu produk yang terdiri dari 19 komponen telah digunakan di dalam penyelidikan ini, dan algoritma *Particle Swarm Optimization* (BPSO) serta algoritma hibrid yang terdiri dari BPSO dan *Differential Evolution* (DE) telah diguna untuk mengira fungsi kecergasan bagi masalah ASP tersebut. Algoritma baru BPSODE dinilai menggunakan kriteria ukuran prestasi. Algoritma BPSODE ini disahkan dengan menggunakan 8 masalah penanda aras yang komprehensif yang ada di dalam literatur. Keputusan menunjukkan bahawa algoritma BPSO mempunyai prestasi yang lebih baik dan boleh mengurangkan lagi masa pemasangan bagi ASP dengan 19 bahagian berbanding dengan algoritma *Simulated Annealing* dan *Genetic Algorithm*. Algoritma hibrid baru BPSODE menunjukkan prestasi yang cemerlang berbanding dengan BPSO apabila dinilai menggunakan kriteria ukuran prestasi. Algoritma BPSODE juga menunjukkan penjanaan nilai rakaman optimum yang bagus bagi 8 masalah penanda aras piawai.

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LIST OF ABBREVIATIONS

ASP	-	Assembly Sequence Planning.
PSO	-	Particle Swarm Optimization.
BPSO	-	Binary Particle Swarm Optimization.
DE	-	Differential Evolution.
BPSODE	-	Binary Particle Swarm Optimization Differential Evolution.
SA	-	Simulated Annealing.
GA	-	Genetic Algorithm.
CAD	-	Computer Aided Design.
NP	-	Nondeterministic Polynomial.
ASTD	-	Assembly State Transition Diagram.
AFI	-	Assembly From Industry.
PCB	-	Printed Circuit Board.
AC	-	Ant Colony.
NN	-	Neural Networks.
EA	-	Evolutionary Algorithm.
GP	-	Genetic Programming.
EP	-	Evolutionary Programming.
ES	-	Evolutionary Strategies.
OGA	-	Ordering Genetic Algorithm.
ALB	-	Assembly Line Balancing.
GSAA	-	Genetic Simulated Annealing Algorithm.
DPSO	-	Discrete Particle Swarm Optimization.
SI	-	Swarm Intelligence.
TSP	-	Travelling Sales Problem.
DEPSO	-	Differential Evolution Particle Swarm Optimization.

BBDE	-	Bare Bones Differentail Evolution.
BPSODE	-	Binary Particle Swarm Optimization Differential Evolution.
PS	-	Pattern Search.
LUS	-	Local Unimodal Sampling.
MOL	-	Many Optimizing Liaisons.
GD	-	Gradient Descent.
FCT	-	Factory Capacity Table.
APM	-	Assembly Precedence Matrix .
OCC	-	Operator Choice Complexity.
CR	-	Crossover.
T	-	Tool changing.
AMOPSO	-	Another Multi-Objective Particle Swarm Optimization.
VEPSO	-	Vector Evaluated Particle Swarm Optimization.
ADI	-	After Diversity Improvement.
SR	-	Success Rate.
AE	-	Average Error.
ACT	-	Average Computational Time.
Eff.	-	Efficiency.
SQ	-	Solution Quality.
SD	-	Standard Deviation.
BFA	-	Best Fitness Accuracy.

LIST OF SYMBOLS

i^{th}	-	i^{th} particle
X_i	-	i^{th} particle is represented by d^{th} dimensional vector
pop	-	The swarm size of n particle are named population
PB_i	-	The individual best position fitness value
GB	-	The swarm global best position
V_i	-	The particle velocity is the rate of change of position
$v_{i,d}^{k+1}$	-	Velocity of i^{th} particle at iteration k+1 and d^{th} dimension
$x_{i,d}^{k+1}$	-	Position at i^{th} particle, iteration k+1 and d^{th} dimension
$v_{i,d}^{k}$	-	Velocity of i^{th} particle at iteration k and d^{th} dimension
$pbest_{i,d}^{k}$	-	The individual best position at iteration k and d^{th} dimension
$gbest_{i,d}^{k}$	-	The swarm global best position at iteration k and d^{th} dimension
$x_{i,d}^{k}$	-	Position at i^{th} particle, iteration k and d^{th} dimension
w	-	Inertia weight
$rand_1$	-	Random value from 0 to 1
$rand_2$	-	Random value from 0 to 1
c_1	-	Cognitive factor
c_2	-	Social factor
d	-	d^{th} dimension of the search space
k	-	k^{th} iteration
PM	-	The Precedence Matrix
FA	-	The Feasible sequence Assembly
Ω	-	Group of parts that assembled earlier than part (j)
part (i)	-	Part to be assembled

part (j)	-	Part already assembled
part (i)	-	a predecessor of part (j)
n!	-	'n' factorial
$T_{Setup}(i)$	-	The time of *setup*
P_{io}	-	Setup time for product i being the first component in the assembly
P_{ij}	-	Contribution to the setup time due to the presence of part j when entering part i
A_i	-	Assembly time for component i.
$Min\ T_{Assembly}$	-	The optimum assembly time
R_j	-	Reorientation
$\forall_{i,j}$	-	For all parts
Z_1	-	Assembly objective function
T_i	-	Tool changing
T	-	Total number of *tool changing*
Z_1	-	Individual objective function 1
Z_2	-	Individual objective function 2
Z	-	Combination of two objective functions
$Min\ Z$	-	Minimization of total objective functions
w_i	-	The indicator weight of the each function
(i)	-	'i' is equal 1 or 2
$v_{ij}(t+1)$	-	Velocity of a particle from location i to j
$V_{\max j}$	-	Max. velocity at j
$c_{1,min}$	-	Min. value of cognitive function c_1
$c_{2,min}$	-	Min. value of Social function c_2
$c_{1,max}$	-	Max. value of cognitive function c_1
$c_{2,max}$	-	Max. value of Social function c_2
$\vec{X}$	-	System performance
$\vec{X}^*$	-	Best system performance evaluated by fitness function
$\Re$	-	Search space
$\Re^D$	-	Search space with D dimensional
$x_j^{(L)}$	-	Lower boundary constraint

$x_j^{(U)}$	-	Upper boundary constraint
(P)	-	Differential Evolution population
P^G	-	Differential Evolution feasible solutions
(N_p)	-	Differential Evolution constant size population N
X_i^G	-	Real valued vector; where :
(i)	-	Indexes the population
(G)	-	The generation to which the population belongs
G_{max}	-	Max. number of population in specific generation
$P^{G=0}$	-	The initial population in generation
$rand_j[0,1]$	-	Uniformly distributed random value within the range: [0.0,1.0]
P^{G+1}	-	Subsequent generation
$u_{j,i}^{G+1}$	-	Trial vector
r_1, r_2 and r_3	-	Random, integer values
$U_{i,G+1}$	-	Trial vector differs from its counterpart in previous generation, $X_{i,G}$
(F)	-	DE control real-valued parameter in binary of value ‘0’ & ‘1’
(CR)	-	DE control real-valued parameter of Crossover
$sigmoid\ (v_{i,d}^k)$	-	Function to map velocity to a probability in the range [0, 1]

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CHAPTER 1

INTRODUCTION

1.1 Background

Assembly Sequence Planning (ASP) is a very well known problem of scheduling of the production process, which has been identified in the field of Computational Complexity Theory as a strongly Nondeterministic Polynomial time problem, and it is considered among the researchers in the field of softcomputing field as a best example of a mathematically complex problem especially when the number of components of a product increased. The essential characteristic of ASP is to find the best sequence of tasks in any assembly process in the assembly line, in order to reduce the time of putting the components together, or cut off the process cost (HongGuang, and Cong, 2010).

The three words assembly sequence planning (ASP) determines the product's parts sequence and the details of the process of the assembly operations that put together each and every individual part of the product into an assembly (Bourjault, 1984; De Fazio and Whitney, 1987; Homen de Mello and Sanderson, 1990; 1991a). The plan of the assembly has a teremendous impact on the production process efficiency and costs. There are products consist of 13 components as illustrated in Figure 1.1.

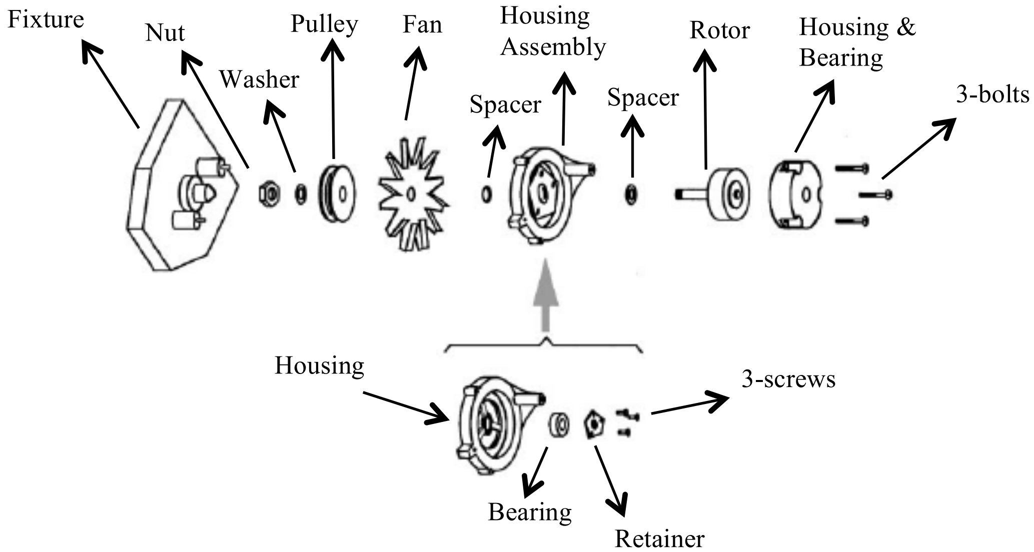

Figure 1.1 An assembly product, which consist of 13 components.
Source: (Hong and Cho, 1999)

The scheduling of production is a complex not perfect process, such that multi-variety, low-batch flow-shop scheduling for makespan minimization become extreme complex and become progressively sophisticated as hundreds of components were engaged (Hejazi and Saghafian, 2005; Kemal et al., 2007). The biggest part of manufacturing workload is assembly. Incorporating design, planning, production, and procurement lead to improvement of product development process by cutoff the time and cost of the developed product. The product order of assembly is the main focus of ASP to determine, which is subjected to a precedence constraint matrix (PM) that is to be strictly followed in the assembly line to shorten the assembly time and concequently minimizing the assembly cost.

1.2 Problem Statement

Sequence planning is an important problem in designing an assembly line. It is to determine an order of assembly tasks to be performed sequencially. The time incurred due to the assembly of the product, play a very important factor in the product cost. The main contribution of this thesis is to minimize the time of assembly, which concequently will lead to a reduction of the product cost.

In assembly planning many parameters must be taken in consideration (Bourjault, 1984; De Fazio and Whitney, 1987; Homen de Mello and Sanderson, 1990; 1991a; 1991b). These parameters are important in the manufacturing process such as the physical geometric design of an assembly must be examined in prior to confirm a sequence that is feasible for assembly; that is the parts does not collide with each other or parts stacking. The assembly process would not be successful without modification to be done to the assembly process.

Assembly sequences for the components in a product that can create the complete product in practice; are those named feasible assembly sequences. Out of all feasible assembly sequences, plan for sequencing assembly is frequently reduced to search for the optimal, or a sub optimal sequence of assembly. The optimum or sub optimum sequence is the sequence with the optimum or a partial optimum for total assembly time, used resources, or combinations of these properties.

A detailed information related to the assembly process during the manufacturing operation is required in order to find the precedence relation between components, that is usually may not be available in the product model. Mainly computer tools are used to gather the relation between components, even though sometimes it could be done through interrogating a human assembly planner. The physical shape description of the assemblage will constitute the inputs to the computer tools, with some times simple interconnections amongst units. The parts interconnections are classified whether these matings are fixed or not and whether components mate with each other (Gottschlich *et al.*, 1994) provided an overview of techniques in assembly sequence planning.

A good assembly sequence can be achieved by considering few parameters such as *tool changing and tool complexity*, *reorientation*, *directionality*, *stability*, *manipulability*, and *parallelism* of assembly operations. Those factors certified a high quality sequence relating to efficient of sequence, costing, assembly safety, and safety of workers in regards to the operations (Homen de Mello and Sanderson, 1991a; Waarts *et al.*, 1992; Ben-Arieh and Kramer, 1994; Xu *et al.*, 1994; Dini and Santochi, 1992; Lee and Ko, 1987; Lin and Chang, 1991). The production engineers target is to make the assembly process more easy, and that objective can be achieved by automating the generation of the assembly process (Ben-Arieh, 1994; Shpitalni *et al.*, 1989; Lee and Shin, 1988; Bullinger and Ammer, 1984; Wolter, 1990; De Floriani, 1989;). The sequence of the assembly is the *spine* of any assembly process, in that sense, generating sequencing automatically is the main target of this research.

In this thesis, the differences between the two terms *parts* and *components* will be explained to avoid confusion, as both terms will be frequently used. A *part* constitues the smallest unit within a product; it cannot be subdivided into smaller units. The set of parts constitues a *component* is stable, i.e. it does not fall into pieces during assembly process. The part is also considered as component because it is always stable.

1.3 Research Objectives

The objectives of this research can be summarized as follows:

1. To formulate and analyse the Assembly Sequence Planning (ASP) model.
2. To minimize the time of assembly sequence using hybrid Binary Particle Swarm Optimization (BPSO) and Differential Evolution (DE) algorithms.
3. The algorithm will be assessed using performance-evaluated criteria, and validated via 8 standard benchmark problems from the literature.

1.4 Research methodology

To date various methods have been developed and introduced to solve the problem of assembly sequence planning (ASP), by minimizing the time of assembly and consequently reducing the cost of manufacturing. It was decided that the best method to adopt for this investigation was to hybrid a two well-known algorithms that are Binary Particle Swarm Optimization (BPSO) and Differential Evolution (DE).

A case study approach which consist of a product consist of 19 components, at which each part of the product assembly was labelled by a number from 1 to 19 without going into the physical diagram details of the product. The table of constraints that restrict the assembly of the parts will ensure the production of feasible sequences. At first a thorough analysis to the formulated ASP model will be performed and the formula would be modified in order to use it in the algorithms of optimization to search for the minimum time of sequences assembly of the product. Any sequences that did not follow strictly the rules of the assembly constraints will be considered as infeasible sequences and should be discarded. The search for feasible sequences will be attchieved by implementing a meta-heuristic algorithm known as binary particle swarm optimization (BPSO). The global best optimum value obtained by the BPSO algorithm will be used as an input to the differential evolution algorithm (DE) to obtain the best minimum value of time.

A standard performance measures from literature will be used to evaluate the efficiency and performance of the hyprid algorithm (BPSODE) compared to Simulated Annealing (SA) and Genetic algorithm (GA) that been used to solve the ASP problem. The algorithm will be validated by using the hybrid algorithm (BPSODE) to solve eight standard problems from the literature.

1.5 Research scope and limitation

1. The investigation is performed on an assembly product from industry that its components to be assembled were labelled by numbers instead of real pictures of the product (Motavalli, S. Islam, A. 1997; Choi *et al.*, 2009).
2. Optimization of the time of total assembly sequences and the total number of tool changing will be considered.
3. The constraints of the assembly design are the precedence relationships between the components subjected to the assembly process.
4. Eight Benchmark functions widely used in the literature will be implemented to validate the algorithm.
5. The programming language implemented is Matlab and Delfi.

1.6 Thesis organization

Chapter 1 provides a brief overview of the assembly sequence planning problem and the previous work done to solve it. The importance of the assembly part of the manufacturing was highlighted, as well the factors that have to be taken strictly into consideration in order to obtain a feasible sequences. Good feasible sequences leads to a minimum value of time of assembly and accordingly reduction of the cost of the manufacturing process. The research scope and limitation were introduced to bring a clear idea about the strength and weaknesses of the research.

Chapter 2 introduced the nature of the ASP problem and the different techniques that have been used by different researchers to tackle the problem. It clarify how the assembly sequences is more difficult than finding disassembly sequences. It introduced briefly the assembly modeling, using CAD and the functional precedence constraints amongst the connections, the exact method used after that, and then provides an overview of the stochastic techniques used, and the meta-heurastic methods implemented to solve ASP.

Chapter 3 explained in more details the methodology implemented in order to solve the ASP problem. First the ASP problem was formulated and analysed mathematically, and the strategies implemented to diversify the feasible sequences obtained by the searching algorithms. The case study used, that consist of 19 components and the parameters that considered, such as the precedence constraints and the coefficient table data implemented. A detailed overview of the particle swarm optimization (PSO), the binary PSO, the differential evolution (DE) and the proposed hybrid method that labelled as (BPOSDE).

Chapter 4 discussed in details the obtained results by the research, and demonstrates the simulation graphs in conjunction with thorough analysis. The results generated by the first to implement (in this thesis); algorithm Binary PSO to solve Assembly Sequence Planning (ASP) is demonstrated, analysed thoroughly, and compared with another algorithm of Genetic Algorithm (GA) and Simulated Annealing (SA), which shows a better optimal time. The result of the novel hybrid algorithm BPSODE is is introduced, and its performance-evaluated criteria are justified, and the algorithm validation is proven through the implementation of standard well known 8 benchmark problems from the literature. The novel algorithm managed to generate the benchmark problems optimum values as recorded in the literature.

Chapter 5 discussed the formula modification of the fitness function of the ASP problem by analysing the actual assembly time of a number of feasible sequences from the literature. It is also discussed the results obtained by Binary PSO in a comparison with genetic algorithm and simulated annealing algorithm in solving the ASP. This chapter discussed the investigation of the effects of the control parameter of PSO algorithm. It summarizes and reflects the major contributions of the proposed approaches BPSO and BPSODE in solving ASP. A discussion was given related to the hybrid algorithm (BPSODE) assessment using performance-evaluated criteria (performance measure), and discussed the algorithm validation by testing the BPSODE via 8 standard benchmark problems from the literature.

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