HYBRID PARTICLE SWARM OPTIMIZATION AND DESIGN OF EXPERIMENT

By

Mai Salah El-Din Abdel Aziz Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
MECHANICAL DESIGN& PRODUCTION ENGINEERING

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FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis:

Hybrid Particle Swarm Optimization and Design of Experiment

Key Words:
Design of experiment; Particle swarm optimization; Hybrid PSO.

Summary:

A hybrid Particle Swarm Optimization algorithm and design of experiment approach is developed and tested. The hybridization between the two methods has two different ways: The first one is a trial to make use of design of experiment to reach the optimum selection and combinations of particle swarm optimization's most significant factors (maximum inertia weight ω_{max}, minimum inertia weight ω_{min}, acceleration coefficients, C_1 and C_2) using 3 levels orthogonal arrays OAs. An L27OA is employed to study the four factors at three levels. The particle swarm optimization is then applied on a number of benchmark problems to find the optimum solution.
The second method is using design of experiments on the problem variables prior to particle swarm optimization. According to the number of parameters of the problem, a suitable orthogonal array is used and number of levels for each parameter is assigned. The obtained feasible solutions are employed as an initial swarm for particle swarm optimization algorithm instead of using large randomly selected swarms.

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I would like to express my very sincere appreciation to Prof. Sayed M. Metwalli for his support to conduct this research.

Dedication

I am dedicating this thesis to my beloved people who have meant and continued to mean so much to me. First and foremost, my parents who have always my nearest and I found them with me whenever I needed. Also, I dedicate this thesis to my husband and my son whose love has no bounds.

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Nomenclature

DOE: Design of experiment
PSO: Particle Swarm Optimization
OA: Orthogonal Array
ANOVA: Analysis of Variance
SS: Statistical Sum
ω: inertia weight
ω_{max}: maximum inertia weight
ω_{min}: minimum inertia weight
χ: constriction factor
p_{best}: personal best position
g_{best}: global best position
SI: swarm intelligence
Mdn: median
SD: Standard deviation
V_{max}: maximum velocity limit
C_1, C_2: acceleration coefficients
GA: Genetic Algorithm
MPSO: Mona Particle Swarm Optimization algorithm (developed in “Particle swarm optimization-applications to small and large scale problems”)
CPSO: competition Particle Swarm Optimization
PSO-CF: Particle Swarm Optimization algorithm using constriction factor
ACO: Ant colony Optimization
ABC: Artificial Bee Colony
SDS: Stochastic Diffusion Search
V_i: Velocity of particle i
Xi: Position of particle i
1^{st}: First formulation
2^{nd}: Second formulation
3^{rd}: Third formulation
4^{th}: Fourth formulation

Abstract

Particle Swarm Optimization (PSO) is an artificial intelligence method that can be used to optimize difficult numeric problems. PSO algorithm uses a number of particles forming a swarm to move around in the search space looking for the best solution.

Taguchi's parameter design is a statistical approach based on design of experiments (DOE). It stresses on the importance of product and/or process improvement to reduce the occurrence of defects and failures in products and/or processes. It is used to lessen time to design new processes and/or products, increase the performance and reliability of a process and/or a product, and to reach product and process robustness.

The objective of this study is to apply Taguchi optimization methodology to Particle Swarm Optimization (PSO) to optimize the value of PSO parameters to achieve optimal solutions. Analysis of variance (ANOVA), and Orthogonal array (OA) are used to study the effect of algorithm parameters. The algorithm parameters are acceleration coefficients C_1, and C_2, maximum inertia weight ω_{max}, minimum inertia weight ω_{min}. A second objective is to optimize the values of the variables of the problem itself and study its effect on optimum solutions.

Three algorithms are used to solve each problem and results are compared. The three algorithms are classified as:

1- Standard PSO in which PSO Algorithm is used without any modifications.
2- Hybrid Algorithm 1 in which DOE is applied on selected PSO parameters by setting 3 levels for each parameter, using random swarm positions and velocities, then solve the problem using PSO.
3- Hybrid Algorithm 2 in which DOE is applied first on the problem variables before applying PSO by setting 3 levels instead of using random values for each variable, then use the obtained feasible solutions as initial swarm for Hybrid Algorithm 1 instead of using large initial swarm size.

The three algorithms are studied with respect to standard test bed problems and three case studies and conclusions are drawn with respect to algorithm efficiency and convergence capability. Using Hybrid Algorithm 2, PSO is able to achieve optimal solutions with smaller swarm sizes and adds more potential to random based techniques. Only non-linear 3 level orthogonal arrays are employed in this thesis as most problems are non-linear in nature. Hybrid Algorithm 1 takes larger CPU seconds than Hybrid Algorithm 2 signifying longer time to convergence. On the other hand, Hybrid Algorithm 2 failed to reach optimum solution in some cases because the swarm size is very small or there is no feasible solution to be considered as initial swarm positions out of all experiments in the used orthogonal array.

Chapter 1: Introduction

In this chapter, Swarm intelligence is introduced. Particle swarm optimization algorithm is shown in details. The Taguchi approach and categorization of variables into controllable and uncontrollable variables are also discussed. Finally, the organization of the thesis is given.

1.1. Swarm Intelligence

Swarm Intelligence (SI) is based on the cooperative behavior of self-organized schemes. The expression was first introduced by Gerardo Beni and Jing Wang in 1989, in the framework of cellular robotic systems [1].

Swarm intelligence systems are classically based on a population of simple agents cooperating locally with one another and with their surroundings. The agents follow very straight forward rules, and although there is no control structure stating how individual agents should behave, local interactions or communications between agents lead to the appearance of complex global behavior. Swarm intelligence systems are robust and simple.

Natural examples of SI include bird flocking, ant colonies, fish schooling, animal collecting, and bacterial growth.

Examples of SI algorithms include Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony Algorithm (ABC), Stochastic Diffusion Search (SDS), and others.

1.2. Particle Swarm Optimization PSO

1.2.1. Introduction

Particle Swarm Optimization (PSO) is an optimization technique initially introduced by Kennedy J and Eberhart R, in 1995. It is a population based optimization algorithm for dealing with problems in which a best solution can be represented in a multi-dimensional space. It is inspired by gathering behavior of fish schools or bird flocks.

PSO method is simple yet powerful tool used in practical fields. Lately, PSO has become one of the most popular optimization techniques for solving optimization problems.

In PSO, the particles are flown through an n-dimensional search space, where the positions of particles are changed according to their own knowledge and their neighbors.

1.2.2. PSO Applications

The earliest application of PSO was in neural network field, many other fields applied it after that include: telecommunications, data mining, design, power systems, and other applications [2].

Important applications include communication networks, the design of engines and electrical motors. Music generation and games are further applications. Computer graphics also have a portion of the applications of PSO. Scheduling applications include generator and transmission maintenance scheduling, flow shop scheduling, optimal operational planning of energy plants, blending scheduling, power generation scheduling, scheduling in battery energy storage systems,