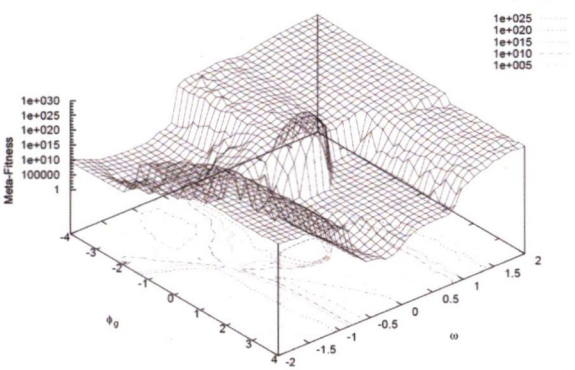
Computer Science, Technology and Applications

Particle Swarm Optimization (PSO)

Advances in Research and Applications



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Particle Swarm Optimization (PSO)

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COMPUTER SCIENCE, TECHNOLOGY AND APPLICATIONS

PARTICLE SWARM OPTIMIZATION (PSO)

ADVANCES IN RESEARCH AND APPLICATIONS

BRIAN WALKER
EDITOR

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PREFACE

Particle swarm optimization (PSO) is one of the recently developed swarm intelligent optimization technologies that offer the advantages of simplicity and fast biological convergence. The technique originated from the theory of artificial life and evolution, which is based on the optimization that is achieved as a result of swarm behaviour. PSO can be easily implemented due to fewer parameters for adjustment hence it has been applied broadly in various engineering fields. This book reviews advances in research and applications of PSO.

Chapter 1 - Minimum-time relative trajectories between two orbiting spacecraft represent a subject of great relevance in astrodynamics, also in consideration of the related applications to formation flying and proximity maneuvers involving two or more space vehicles. This work uses the Hill-Clohessy-Wiltshire linear equations of motion to model the spacecraft dynamics, and employs a Hamiltonian approach for the determination of optimal relative trajectories. Specifically, the orbital interception problem involving two maneuvering vehicles is considered. If both of them intend to minimize the time until interception, then the problem can be formulated as an optimal control problem. In the presence of a pursuing vehicle and an evading target, which aims at delaying interception indefinitely, then the problem is formulated as a zero-sum differential game. In the latter case, the optimal trajectories of the two space vehicles correspond to a saddle point equilibrium solution. The necessary conditions either for an optimal solution or for an equilibrium solution are derived for the two cases of cooperating and competitive spacecraft, respectively. These conditions allow translating the original problems into parameter optimization problems with a fairly reduced parameter set, mainly composed of the unknown initial values of the adjoint

variables. A basic version of particle swarm algorithm is then employed, and proves effective and accurate in finding the optimal values of the unknown parameters, thus identifying the optimal trajectories and the related control laws, either when the two spacecraft cooperate or when they are involved in a competitive scenario.

Chapter 2 - The increased demand for the electricity arises request for providing high-quality power with constant voltage and frequency. Moreover, in the interconnected power system, the main desired objective is the high-quality power exchange between areas over interconnecting tie lines. To achieve high quality active and reactive powers, the Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR) should be considered. The desired objectives in this chapter are designing the area LFC to have some degree of control over tie-line power flow and frequency of individual areas and also maintaining a constant voltage over it using AVR. It is important to properly design the area LFC and AVR to improve both the quality and reliability of the electricity delivered to consumers. In the actual power systems, there exist nonlinearities such as parameters variations and Generation Rate Constraints (GRC) for generating units which are considered in this chapter. Accordingly, the controller obtained for LFC as well as AVR based on Particle Swarm Optimization (PSO) are proposed since those techniques are capable of dealing with nonlinear models.

This study proposes both I and PID controllers for LFC and AVR using various types of PSO. A comprehensive comparative study is performed to prove the effectiveness of the proposed PSO based controllers. Simulation results proved the capability of the proposed controllers to deal with small load disturbance as well as a large disturbance in the presence of GRC.

In this chapter, there are different kinds of PSO are introduced like Time-Varying Initial Weight, Constrictive, Adaptive Acceleration Coefficients and Modified Adaptive Acceleration Coefficients Particle Swarm Optimization to obtain the optimal gains.

Chapter 3 - Particle swarm optimization (PSO) is one of the recently developed swarm intelligent optimization technologies that offer the advantages of simplicity and fast biological convergence. The technique originated from the theory of artificial life and evolution, which is based on the optimization that is achieved as a result of swarm behaviour; for example, birds seeking their optimal location and global optimal location during food searching simultaneously. PSO can be easily implemented due to fewer parameters for adjustment hence it has been applied broadly in various engineering fields.

This chapter reviews the development of the PSO algorithm and its application to the power systems. Firstly, the basic principle of the PSO is briefly introduced. Then related PSO algorithms combined with other heuristic algorithms are explained, including BPSO, APSO, QPSO, and other hybrid PSO algorithms. Common constraints and multi-objective problems that occurred in the applications are also considered. Furthermore, the solution of the three typical combination issues in power systems, i.e., TSP, QAP, and Knapsack via various types of PSO algorithms, is presented. In addition, the applications of PSO to power systems, such as power grid planning, maintenance, short-term power generation, and unit combination, are discussed in detail. Examples in each applied direction are also provided. Finally, the prospect of PSO in power engineering is summarized.

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Chapter 1

PARTICLE SWARM OPTIMIZATION OF COOPERATIVE AND COMPETITIVE RELATIVE ORBIT MANEUVERS

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ABSTRACT

Minimum-time relative trajectories between two orbiting spacecraft represent a subject of great relevance in astrodynamics, also in consideration of the related applications to formation flying and proximity maneuvers involving two or more space vehicles. This work uses the Hill-Clohessy-Wiltshire linear equations of motion to model the spacecraft dynamics, and employs a Hamiltonian approach for the determination of optimal relative trajectories. Specifically, the orbital interception problem involving two maneuvering vehicles is considered. If both of them intend to minimize the time until interception, then the problem can be formulated as an optimal control problem. In the presence of a pursuing vehicle and an evading target, which aims at delaying interception indefinitely, then the problem is formulated as a zero-sum differential game. In the latter case, the optimal trajectories of the two space vehicles correspond to a saddle point equilibrium solution. The necessary conditions either for an optimal solution or for an equilibrium solution are derived for the two cases of cooperating and competitive

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spacecraft, respectively. These conditions allow translating the original problems into parameter optimization problems with a fairly reduced parameter set, mainly composed of the unknown initial values of the adjoint variables. A basic version of particle swarm algorithm is then employed, and proves effective and accurate in finding the optimal values of the unknown parameters, thus identifying the optimal trajectories and the related control laws, either when the two spacecraft cooperate or when they are involved in a competitive scenario.

Keywords: Relative orbit motion, Hill-Clohessy-Wiltshire equations, Satellite interception maneuvers, particle swarm optimization, indirect heuristic method

1. INTRODUCTION

Minimum-time relative trajectories between two orbiting spacecraft represent a subject of great relevance in astrodynamics, also in consideration of the related applications to formation flying and proximity maneuvers involving two or more space vehicles. In general, the determination of optimal (either minimum time or minimum consumption) space trajectories has been pursued with different approaches, for decades. Classical numerical optimization techniques are usually classified as indirect, direct, or hybrid approaches. While indirect methods [1-5] employ the analytical conditions that arise from the calculus of variations, direct techniques [6-9] convert the optimization problem into a nonlinear programming problem (often involving a large number of parameters). Hybrid approaches [10] combine direct and indirect techniques, usually by replacing some difficult conditions that arise from the calculus of variations with some simplified relations. A survey of these methods is provided by Betts [11] and, most recently, by Conway [12].

These three types of techniques belong to the class of "deterministic" methods, as opposed to "heuristic" or "stochastic" techniques. With regard to convergence, in general direct techniques are more robust, because they are often capable of converging to the desired result even in the presence of a poor guess. Conversely, indirect methods are more numerically accurate and do not need any parameterization of the time-varying quantities involved in the problem of interest. Both direct and indirect algorithms are relatively fast and accurate in yielding an optimal solution. However, two intrinsic features of deterministic approaches that represent their main limitations are (a) the need of a starting guess, and (b) locality of the results. In fact, both direct and

indirect methods are local in nature, in the sense that the optimal solution they are able to identify depends on the available first attempt approximate "solution." The numerical result found by deterministic techniques usually lies in the proximity of the guess.

These circumstances have motivated the development of heuristic optimization techniques, usually inspired by natural phenomena. Heuristic methods exploit a population of individuals, representing possible solutions to the problem of interest. The initial population is randomly generated, and therefore no guess is to be provided. The optimal solution is sought through cooperation and competition among individuals. The most popular class of these techniques is represented by the genetic algorithms [13], which model the evolution of a species, based on Darwin's principle of survival of the fittest. Applying heuristic algorithms to optimal control problems requires their preliminary conversion into parameter optimization problems, if possible with a moderate number of unknown parameters. In fact, as the dimensionality of the parameter set increases, the population size must increase to obtain a satisfactory performance, especially in terms of the algorithm capability of exploring the search space, where the unknown parameters are sought. In most cases, the state variables are obtained through numerical integration, while the control variables are usually represented by means of a finite number of parameters, for instance using polynomial functions of time [14]. The main disadvantage in using heuristic approaches is in the fact that no guarantee of converging to an optimal solution exists. In fact, in general no analytical proof exists about convergence of a heuristic method, even to a locally minimizing solution. The effectiveness of heuristic approaches is instead based on the likelihood of converging to the globally minimizing solutions of qualitatively different problems, and extensive numerical tests are to be performed for evaluating the performance of any new algorithm.

The work that follows describes and applies a general optimization methodology, based upon the joint use of the analytical conditions for an optimality and a heuristic technique (in this study, the particle swarm optimization algorithm [15], described in Section 2). Specifically, the necessary conditions for optimality are employed to express the control variables as functions of the adjoint variables, which are subject to the costate equations (and the related boundary conditions). As a result, a reduced parameter set (mainly composed of the unknown initial values of the adjoint variables) suffices to transcribe the optimal control problem into a parameter optimization problem. Furthermore, the optimal control variables are determined without any restriction, because no particular representation is

assumed. Lastly, satisfaction of all the necessary conditions guarantees the (local) optimality of the solution. This methodology, termed indirect heuristic algorithm [16-17], is thus capable of circumventing the main disadvantages of using heuristic techniques, while retaining the main advantage, which is the absence of any starting guess. The main reason for using a swarming algorithm is in its simplicity. In fact, the basic version of the particle swarm algorithm (PSO) appears as very intuitive, and is extremely easy to program. The indirect heuristic method (IHM) has already been successfully applied to a variety of spacecraft optimization problems [14, 16-20].

This chapter presents also the application of IHM to competitive scenarios involving two spacecraft with conflicting objectives. This dynamical situation is to be modeled as a zero-sum differential game, and the related solution is termed saddle point equilibrium solution. The analytical conditions for an equilibrium solution can be regarded as an extension of the respective conditions that hold in optimal control theory. Their use, in conjunction with a heuristic technique (PSO in this work) represents the theoretical premise for the application of the indirect heuristic method to dynamical competitive contexts.

Specifically, this chapter describes and applies the indirect heuristic method to solving two different relative orbit maneuvering problems:

1. *Interception maneuvers between two cooperative spacecraft*. The problem consists in determining the optimal thrust magnitude and direction for two space vehicles in close proximity. Each spacecraft intends to reach the other one as fast as possible. Therefore, both vehicles have the same objective, and the problem is formulated as an optimal control problem.
2. *Interception maneuvers between two competitive spacecraft*. The problem involves two spacecraft with conflicting objectives: while the pursuing spacecraft aims at reaching the target vehicle as fast as possible, the latter tries to delay interception indefinitely. This dynamical scenario is correctly modeled as a zero-sum differential game. The optimal thrust magnitude and direction of each spacecraft correspond to a saddle point equilibrium solution.

This chapter is thus intended to (a) describe IHM as the combination of the analytical conditions (either for an optimal or a saddle-point equilibrium solution) with a heuristic algorithm (PSO in this study), and (b) prove that IHM, despite its intuitiveness and simplicity, is capable of effectively solving

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