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Discrete Optimization

A hybrid adaptively genetic algorithm for task scheduling problem in the phased array radar

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ABSTRACT

A phased array radar (PAR) is used to detect new targets and update the information of those detected targets. Generally, a large number of tasks need to be performed by a single PAR in a finite time horizon. In order to utilize the limited time and the energy resources, it is necessary to provide an efficient task scheduling algorithm. However, the existing radar task scheduling algorithms can't be utilized to release the full potential of the PAR, because of those disadvantages such as full PAR task structure ignored, only good performance in one aspect considered and just heuristic or the meta-heuristic method utilized. Aiming at above issues, an optimization model for the PAR task scheduling and a hybrid adaptively genetic (HAGA) algorithm are proposed. The model considers the full PAR task structure and integrates multiple principles of task scheduling, so that multi-aspect performance can be guaranteed. The HAGA incorporates the improved GA to explore better solutions while using the heuristic task interleaving algorithm to utilize wait intervals to interleave subtasks and calculate fitness values of individuals in efficient manners. Furthermore, the efficiency and the effectiveness of the HAGA are both improved by adopting chaotic sequences for the population initialization, the elite reservation and the mixed ranking selection, as well as designing the adaptive crossover and the adaptive mutation operators. The simulation results demonstrate that the HAGA possesses merits of global exploration, faster convergence, and robustness compared with three state-of-art algorithms—adaptive GA, hybrid GA and highest priority and earliest deadline first heuristic (HPEDF) algorithm.

1. Introduction

A radar sensor utilizes reflections of transmitted electromagnetic waves to detect the incoming targets and update the information of previously detected targets. The cycle over which the radar transmits energy, waits and receives the reflected energy, is defined as a task. It is often the case that, especially in the modern battlefield, various tasks need to be performed by radar sensors in a finite time horizon, such as communications, tracking targets and searching horizons. Such various tasks should be performed by multiple traditional mechanically rotating radars, each of which is responsible for a single and dedicated function/task. By contrast, owing to its agile beam pointing directions, a single phased array radar (PAR) is capable of handling the different tasks above. However, such remarkable advantages depend on the efficient time management.

The research on how to chronologically order and perform multiple tasks leads to the task scheduling problem, and it has been investigated in various studies. Herr and Goel, (2016) and Oron, Shabtay, and Steiner (2016) address the single machine scheduling problem with family setups or two competing agents. Sioud and Gagné (2018) presents an enhanced migrating bird optimization (MBO) algorithm and a new heuristic for solving a permutation flow shop scheduling problem with sequence dependent setup times. Pessoa and Andrade (2018) addresses the flow shop scheduling problem with delivery dates and cumulative payoffs and suggests the biased random-key genetic algorithm starting with a solution from FF heuristic after comparison. Moukrim, Quilliot, and Toussaint (2015) proposes an effective branch-and-price algorithm for solving preemptive resource constrained project scheduling problem based upon minimal interval order enumeration involving column generation as well as constraint propagation. Shioura, Shakhlevich, and Strusevich (2018) provides a review of recent results on preemptive scheduling with controllable processing times. Just similar with the scheduling problems above, the PAR task scheduling is able to be regarded as a preemptive flow

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shop scheduling problem in single machine subject to the time and the energy constraints. A radar task consists of three subtasks: the transmit interval, the wait interval and the receive interval, and the execution of each task needs a certain duration and power consumption. Obviously, the PAR task scheduling problem is N-P hard. Within the context of radar sensors, the solutions to the problem can be divided into two parts: the heuristic algorithms and the meta-heuristic algorithms. In the heuristic algorithms, each task is assigned for a priority and the request tasks are orderly scheduled from the highest priority. However, such algorithms only explore the solution region by one path while ignoring other paths. Therefore, they can't provide consistent results for wide ranges of problems. By contrast, the meta-heuristic algorithms exploit the swarm cooperation and continuous evolution to explore solutions in the whole solution region, and thus are able to obtain near-optimal results. The typical heuristic algorithms are the earliest deadline first (EDF) algorithm (Butler, 1998; Reinosorondinel, Yu, & Torres, 2010) and the highest value first algorithm (Deb, Bhattacharjee, & Vengadarajan, 2015; Orman, Potts, Shahani, & Moore, 1996; Sgambato, Celentano, Dio, & Petrillo, 2016). However, these algorithms only prioritize the request tasks by a single parameter, and such prioritization may be one-sided. Huizing and Bloemen (1996), Jiménez, Izquierdo, Villacorta, and Val (2009), Jimenez, Val, Villacorta, and Izquierdo (2012) divide the tasks into several queues by ordinations and task parameters, and the EDF algorithm or the first in first out (FIFO) algorithm is used in each queue. Cheng, He, and Li (2009), Cheng, He, and Tang (2009), Lu, Xiao, Xi, and Zhang (2011), Lu, Xiao, Xi, and Zhang (2013) map the task mode and the deadline to the same layer to calculate the task synthetic priority and prior schedule the task with the highest synthetic priority. On the basis of the two elements in Chen, Tian, Wang, Zhang, and Cao (2011), Cheng et al. (2009), Cheng, He, & Tang (2009), Lu et al. (2011), Lu et al. (2013), and Cheng, He, and Tang (2008) further take the timeliness principle of task scheduling into consideration and propose the gain-based scheduling algorithm. Zhang, Xie, and Sheng (2016a); Zhang, Xie, Zong, Lu, and Sheng (2017) exploit the threat of the target to represent the task importance and offer the dynamic-priority-based scheduling algorithm. These algorithms all prioritize tasks by multiple task parameters, and such a prioritization is more reasonable. In addition, Mir and Abdelaziz (2012) and Mir and Guitouni (2014) put forward the notion of the variable dwell time, which brings more flexibility for the task scheduling. In meta-heuristic algorithms, Pan (2014), Wang, He, Wang, and Ji (2014), Zhang, Xie, and Sheng (2016b), Zheng, Tian, and Xing (2016), Zhou, Wang, and Wang (2005), Zhou, Wang, and Wang (2006) apply the improved genetic algorithms (GAs) to the radar task scheduling problem, which renders the improvement of the steadiness and the robustness.

While the existing work has made many seminal contributions to the radar task scheduling, there are still some issues to be addressed. Firstly, some algorithms (Butler, 1998; Deb et al., 2015; Huizing, & Bloemen, 1996; Jimenez et al., 2012; Jiménez et al., 2009; Lu et al., 2011; Lu et al., 2013; Mir, & Abdelaziz, 2012; Pan, 2014; Reinosorondinel et al., 2010; Sgambato et al., 2016; Wang et al., 2014; Zhang et al., 2016a; Zhang et al., 2017; Zheng et al., 2016) just model the task structure as the non-preemptive. The full radar task structure, which includes the transmit, wait and receive subtask is not considered. This precludes exploiting the wait subtask to interleave other subtasks and making a more efficient utilization of the radar timeline. Secondly, though some algorithms (Chen et al., 2011; Cheng et al., 2009; Cheng et al., 2008; Cheng et al., 2009; Mir, & Guitouni, 2014; Orman et al., 1996; Zhou et al., 2005; Zhou et al., 2006) model a full radar task structure and utilize the wait interval to interleave subtasks, the optimization model of task scheduling is not posed or the algorithms only try to achieve a simple goal such as maximizing the number of scheduled tasks or the time utilization. Due to the inherent characteristics of radar task scheduling, such a simple objective function is not able to guarantee the performance in multiple aspects. For example, tasks with higher priority may be simultaneously with longer dwell time and thus, the sum priority of successfully scheduled tasks and the number of successfully scheduled tasks in a finite time horizon are conflicting. Thirdly, most of the works (Butler, 1998; Chen et al., 2011; Cheng et al., 2009; Cheng et al., 2008; Cheng et al., 2009; Deb et al., 2015; Huizing, & Bloemen, 1996; Jimenez et al., 2012; Jiménez et al., 2009; Lu et al., 2011; Lu et al., 2013; Mir, & Abdelaziz, 2012; Mir, & Guitouni, 2014; Orman et al., 1996; Pan, 2014; Reinosorondinel et al., 2010; Sgambato et al., 2016; Wang et al., 2014; Zhang et al., 2016a; Zhang et al., 2017; Zheng et al., 2016; Zhou et al., 2005) just adopt one kind of algorithm (heuristic or meta-heuristic) to solve the problem. The superiorities of the two kinds of algorithms are not well balanced.

An exact optimization model of PAR task scheduling and a hybrid chaotic adaptively genetic algorithm are put forward aiming at these issues. The main contributions of this paper are summarized as follows:

(1) The full PAR task structure, which consists of the transmit interval, the wait interval and the receive interval, is explicitly modeled, and the task scheduling optimization model for the PAR, whose objective function integrated the scheduling principles of the importance, the urgency and the timeliness, is established. As such, the performance of the algorithm in multiple aspects are compromised and guaranteed.
(2) An improved scheduling method over chaotic adaptively GA is proposed to solve the problem. On the basis of the GA, chaotic sequences are introduced to initialize the population. Chaos system is essentially a nonlinear system full of bounded unstable dynamic behavior and infinite unstable periodic motions (Singh, & Mahapatra, 2016; Yao, Liu, & Lin, 2002). As such, chaotic sequences, carrying with the properties of the randomness and the ergodicity of the chaos system, are able to diversify the initialized population. The elite reservation and the mixed ranking selection operation are adopted to prevent the premature convergence of the algorithm. In addition, the adaptive crossover operator and the adaptive mutation operator are both designed to improve the global exploration ability and the efficiency of the algorithm.
(3) A task interleaving scheduling heuristic is presented in the chaotic adaptively GA framework. The task scheduling is considered in a way that the wait interval can be utilized to transmit or receive subtasks as well as the collision between the transmit interval and the receive interval is prevented while satisfying the energy constraint. The heuristic exploits the time constraint feasibility check and the energy feasibility check to analyze the task schedulability, and adaptively interleaves tasks as many as possible. Thereby the fitness value of individual can be quickly calculated and the efficiency of the whole algorithm can be further improved.
(4) Through experimental results over randomly generated tasks as well as closely real-world situations with various task scales, the effectiveness and the efficiency of the proposed algorithm are both verified.

The reminder of this paper is organized as follows. The optimization model of PAR task scheduling is established in Section 2. A hybrid chaotic adaptively genetic algorithm is presented in Section 3. Section 4 gives the simulation results and analysis. Section 5 concludes the paper.