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An Entropy-based PSO for DAR task scheduling problem

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HIGHLIGHTS

- First paper to address DAR task scheduling by meta-heuristic algorithm.
- Optimization task scheduling model for digital array radar.
- Modified PSO and heuristic task interleaving algorithm are integrated for solution.
- Chaotic sequences for initialization, ShannonâĂŹs entropy for self-tune parameters.
- Proposed algorithm outperforms three state-of-the-art scheduling algorithms.

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ABSTRACT

This paper addresses the task scheduling problem in the digital array radar (DAR), which determines the optimal execution order of all tasks subject to precedence and resource constraints. The aim is to achieve good performance in multiple aspects. To our best knowledge, the existing scheduling algorithms, neglecting the task internal structure, not posed as an optimization model, and only utilizing the heuristic method or the meta-heuristic method to solve the problem, cannot fully give free rein to the DAR capability of handling various tasks. Therefore, for such an N-P hard problem, an integer programming optimization model and a hybrid particle swarm optimization (PSO) algorithm are proposed. In the optimization model, a full radar task structure is established, and a comprehensive objective function is formed to guarantee the performance in multiple aspects. In the hybrid PSO, a modified PSO is incorporated to explore good scheduling schemes, and a heuristic task interleaving algorithm, embedded in the PSO framework, for the efficient task schedulability analysis. Moreover, the chaotic sequences are adopted to improve the quality of initialized solution. The Shannon's entropy is introduced to indicate the diversity of the population and adaptively tunes the parameters. Simulation results show that the proposed algorithm outperforms the three state-of-the-art scheduling algorithms while maintaining a reasonable runtime.

1. Introduction

The cycle over which the radar transmits energy, waits and receives the reflected energy, can be defined as a task. Faced with the increasing complexity of modern battle environment, a single radar needs to perform more diverse tasks. As such, the digital array radar (DAR) is developed. Compared with the traditionally analogs phased array radar, the DAR has competitive advantages over serving multiple tasks. However, such advantages are dependent on the efficient scheduling algorithm.

How to chronologically order and perform request tasks has been studied in different contexts [1–4]. However, in radar sensors, the following features should be highlighted. (1) Each request task consists of three subtasks, and different tasks are with different durations. (2) Each task must be performed in its time window because of the target maneuver. (3) There are priority relationships between tasks. (4) The energy constraint must be considered. For such an N-P hard problem, many heuristic methods or meta-heuristic methods have been put forward. In former ones, the resource is assigned to tasks by the preset rules, where the highest task mode priority first [5–7] and the earliest deadline first [8–10] are typical ideas. However, references [11–15] calculate the task synthetic priority by exploiting the two elements. The task with the highest priority is prior scheduled. References [16,17] introduce the threat of the target and set all tasks into dynamic priorities. The task with the highest dynamic priority is prior considered. Based on [11–15], references [18,19] bring in the scheduling principle of timeliness, and structure the gain-based scheduling algorithm.

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Additionally, [20,21] put forward the notion of variable dwell time, and propose the sequential heuristic algorithm. [22–24] introduce the mission of imaging, enriching the radar task scheduling scope. [25–27] address the problem of how to improve the whole resource utility. [28] extends the task scheduling to the multiple channel radar. [29] designs the adaptive time window during scheduling tasks. The heuristic algorithms possess low computational burden. However, suboptimal solutions are usually obtained. Meanwhile, the solutions are far from satisfactory when faced with large size problems. By contrast, meta-heuristic algorithms are able to find out better solutions through the swarm cooperation and the iterative exploration. For example, the improved genetic algorithm (GA) [30–32], the tabu search algorithm [33] and the hybrid genetic particle swarm algorithm [34] have shown their steadiness and efficiency for this problem.

Though the existing works approach the radar task scheduling problem from different aspects, there are still some issues to be addressed.

(1) Some of them [6–10,14–17,20,22,23,25–30,32] treat radar tasks as non-preemptive ones. It prevents the wait interval of the internal task structure being utilized for interleaving subtasks.

(2) Works [5,11,18,19,21,24,31,33,34] do model the full task structure and use the wait interval to interleave subtasks, but full superiorities of the DAR cannot be released yet. In the analog phased array radar, single subtask is transmitted or received at one time. However, owing to the digital beamforming technique, multiple subtasks are able to be received simultaneously by the DAR. Therefore, multiple receive intervals can be overlapped on the timeline. Though [12] and [13] take such characteristic into account, the optimization model is not posed. Additionally, the tasks with the same repetition interval are just interleaved in [12,13], leading to much idle time left on the radar timeline.

(3) The heuristic algorithm or the meta-heuristic algorithm is only used in most literatures [5–30,32,33]. The advantages of both kinds of methods are not well balanced.

Particle swarm optimization (PSO) algorithm, a nature-inspired optimization method, has been involved in intensive research owing to its simple structure and easy application. However, the PSO suffers from the inherent drawback of premature convergence. In order to improve the quality of solutions, many techniques are proposed, such as changing update mechanisms [35–40], multiple particle swarm interaction and cooperation [41–44], and integration with other swarm algorithms [45–50]. By using rotational and translational motions, the multi-objective vortex PSO is presented in [35]. The fuzzy logic is applied to PSO in [36], and the parameters are dynamically adapted. A unification factor is suggested in [37] to balance the effects of cognitive and social terms. [38] presents a distribution-based update rule. [39] compares a number of velocity update equations. [40] proposes pairwise competitions for the PSO. However, these algorithms focus on a single swarm. When the PSO is divided into several groups, the performance can also be improved by the group collaboration. [41] assigns different searching strategies to different swarms. [42] assembles different PSOs for solving complex problems. [43] selects specific evolutionary method for each subgroup of PSOs. [44] classifies particles into ordinary sub-swarm and communication sub-swarm, each of which is responsible for the specific task. As to the combination with other swarm algorithms, the GA is widely adopted. In [45–50], various crossover operators are designed and simulation results demonstrate their effectiveness. Additionally, many PSO variants are put forward for diverse areas, such as cancer classification [51], data allocation [52], wireless sensor network localization [53] and different scheduling problems [54–57]. The extensive study provides a solid foundation for applying the PSO to the DAR task scheduling problem for the first time. As such, in order to address the three issues above, an entropy-based PSO algorithm is put forward. The main contributions of this paper are as follows.

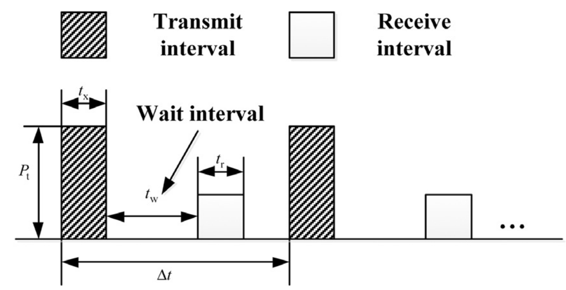

Fig. 1. DAR task structure.

(1) The optimization DAR task scheduling model is developed, where a full radar task structure and a comprehensive objective function are considered. The task scheduling frame is established in a way that wait intervals can be utilized to interleave subtasks, and multiple receive intervals can be overlapped. Additionally, due to the characteristics of radar tasks, a simple objective function [20,21,30,33], such as maximizing the total time utility or the sum of priority of successfully scheduled tasks, cannot ensure good performance in multiple aspects. For example, the task with higher priority may be also with longer duration, resulting in the two performance metric indexes cannot be achieved simultaneously. Therefore, the performance in multiple aspects is compromised, and a comprehensive objective function is established by the integration of the scheduling principles.

(2) A modified PSO is proposed for the solution to the optimization model. The chaotic sequences are utilized to obtain high quality of initialized solutions. Additionally, Shannon's entropy is introduced to indicate the diversity of the population and adaptively tune the inertia weight, the crossover probability and the mutation probability. Therefore, the exploitation capability and the exploration capability are both enhanced.

(3) A heuristic task interleaving algorithm, embed in the PSO, is put forward for the fitness value calculation. The heuristic algorithm decomposes the resource constraint analysis into the time and the energy feasibility checks, as well as interleaves DAR tasks as many as possible. Thereby, the radar timeline can be utilized more effectively and the fitness value can be provided more efficiently.

(4) A large-scale simulation results demonstrate that the proposed algorithm outperforms three state-of-the-art scheduling algorithms while maintaining a reasonable runtime.

The rest of the paper is organized as follows. Section 2 establishes the optimization task scheduling model for the DAR. Section 3 presents an efficient entropy-based PSO for the optimization model. Section 4 discusses the behavior of the proposed algorithm through simulations. Section 5 concludes the paper.

2. Problem descriptions

2.1. Task structure in DAR

A typical DAR task, as shown in Fig. 1, consists of three subtasks: the transmit interval, the wait interval and the receive interval. Number k task can be described by:

$$T_k = \{P_k, t_{ak}/t_{ek}\ , t_{xk}, t_{wk}, t_{rk}, P_{tk}, t_{dwk}, w_k, t_{dk}, \Delta t_k\} \tag{1}$$

The important parameters and explanation are shown in Table 1.