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Review

Solving the dynamic traveling salesman problem using a genetic algorithm with trajectory prediction: An application to fish aggregating devices

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ABSTRACT

The paper addresses the synergies from combining a heuristic method with a predictive technique to solve the Dynamic Traveling Salesman Problem (DTSP). Particularly, we build a genetic algorithm that feeds on Newton's motion equation to show how route optimization can be improved when targets are constantly moving. Our empirical evidence stems from the recovery of fish aggregating devices (FADs) by tuna vessels. Based on historical real data provided by GPS buoys attached to the FADs, we first estimate their trajectories to feed a genetic algorithm that searches for the best route considering their future locations. Our solution, which we name Genetic Algorithm based on Trajectory Prediction (GATP), shows that the distance traveled is significantly shorter than implementing other commonly used methods.

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1. Introduction

The Traveling Salesman Problem (TSP) probably represents the most intensive area of research within the wide range of combinatorial optimization problems [20,24]. Whereas the diverse perspectives and problem-solving methods have helped practitioners and scholars to address a multitude of different problems in different industries [21,33,14,13], the literature on TSP is still underdeveloped with regard to moving targets—such as in the fishing or military industries [26]. In this case, the most recent approaches (which can be grouped under the heading "Dynamic Traveling Salesman Problem"—DTSP) work on a real time basis to find the changes between nodes [40]; nevertheless, they do not anticipate the future movement of targets, so the optimal solution is given only when changes happen and the algorithm is subsequently recalculated.

With this academic background in mind, we faced the problem of tuna vessels that pick up fish aggregating devices (FADs) at sea. When FADs transmit information on how much tuna might be available beneath them, the vessels need to design a route taking into consideration that FADs are constantly moving. They need to minimize distance while recovering the FADs because saving time and fuel determines their competitiveness. Using therefore real data, the paper contributes to the literature by proposing a new approach that combines a heuristic method with a predictive technique. Particularly, we first estimate the trajectories of the FADs to subsequently build a genetic algorithm that uses this information and searches for the best possible route considering their future locations.

From all heuristic methods, we chose GAs for their properties (they are evolutionary, show statistical convergence, and tend to a global optimum with considerable robustness) and because they offer vessels the possibility to reach a solution within an acceptable computational time [30,6]. On the other hand, we chose Newton's movement equation as a predictive technique (we show a performance comparison with other techniques for illustrative purposes) because it offers vessels a sound and quick forecast of the future position of FADs with very little information. By combining both tools in a single method, which could be named Genetic Algorithm based on Trajectory Prediction (GATP), we reach a global optimization solution with statistically better results than those offered by commonly used methods, such as the Nearest Neighbour (NN) strategy or simple Genetic Algorithms (GA) [32,43].

The following section presents a survey of the relevant literature that guides our approach. Section 3 describes the tuna vessels FAD recovery problem. Section 4 compares different prediction models in order to show that the final choice (in our case Newton's motion equation) depends on the specific characteristics of each forecasting initiative. Section 5 shows the experimental design, Section 6 discusses results and, finally, Section 7 concludes highlighting the main contributions of the paper and their implications.

2. Literature review

Calculating the optimal route for recovering N moving elements lies within the Traveling Salesman Problem (TSP) [24]. Given a list of cities and their pairwise distances, the task is to find the shortest possible route to visit each city only once and then return home [1]. Not surprisingly, the initial applications to real world problems were mainly in transportation and logistics [12].

Scholars soon perceived, however, that further applications could be feasible if they interchanged the city concept with, for example, soldering points or DNA fragments, and the distance concept with other constraints like traveling times, cost or time windows. Further developments thus appeared in such diverse fields as crystal structure analysis [7], the drilling of printed circuit boards [22] or even the mapping of a mouse genome [2]. Certainly, the diverse applications also triggered the development of new problem-solving methods [48], from exact algorithms to metaheuristics [8], such as Swarm Intelligence [9] or GAs [13].

GAs represent in fact one of the most consolidated approaches to the TSP [41]. They were first introduced by Holland [27] to generate solutions for optimization problems using techniques inspired by natural evolution [50], leading to many theoretical developments over the last thirty years [44,47].

Basically, GAs achieve the optimal solution from a random set of initial solutions called population. Each set comprises an array of numbers where each number represents one of the targets on the route, which are named genes. Hence, each population is evaluated by a fitness measure (in our study, for instance, the measure is determined by the minimal distance between all points on each route), so parents of the next generation are selected probabilistically from the whole population so that the best routes are selected to become the parents of the next generation. The process is regulated by operators reflecting typical gene traits such as *crossover* and *mutation*. GAs repeat this loop until they converge to a near global optimal.

Recently, some scholars have intensified the use of GA to implement theoretical developments in different fields of application such as ship routing with time deadlines [31], vehicle routing with time windows [15,18,49,4] and vehicle routing with loading constraints [45]. Despite the progress that implementing GAs brought to the literature on route optimization, however, their potential has not been fully exploited when addressing the TSP with constantly moving targets.

GAs generate near-optimal solutions only when cities are at time $t=0$; but, in a dynamic scenario, the salesman needs to decide a route for $t=1$, $t=2$, etc. The final route that the salesman should follow is therefore necessarily different from the one chosen by a conventional approach to static objectives. This is probably the reason why recent literature has increasingly dealt with dynamic targets, leading to a new line of research in this field since Pasraftis [42] introduced a first reflection on the Dynamic Traveling Salesman Problem (DTSP).

Some contributions compare DTSP and TSP and reflect on basic issues to solve the problem, appropriate approaches, or key evaluation criteria [28,55]. Most of the literature, however, presents specific applications based on well-known metaheuristics such as Ant Colony Optimization [16,23], Simulated Annealing [29], Tabu Search [17] and Genetic Algorithms [37,53,35], under which we can also include particular offshoots like inver-over operators [34,51] or CHC Algorithms [46]. All this work represents a generalization of TSP in which targets are not necessarily static and applications are often formulated with time-dependent variable constraints.

Taking this background into account, our approach resembles that of the existing literature on DTSP but differs in an important way. Both assume the dynamic nature of targets, but the available DTSP solutions work basically on a real time basis to find the changes between nodes [55,25]. The main DTSP methods [40]