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Metaheuristic based solution approaches for the obstacle neutralization problem ☆

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ABSTRACT

The problem of finding shortest path under certain constraints is NP-Complete except for some trivial variants. In this study, we develop metaheuristics for the obstacle neutralization problem (ONP) which is a path planning problem where the goal is to safely and swiftly navigate an agent from a given source location to a destination through an arrangement of potential mine or threat discs in the plane. To solve the ONP, ant system, genetic algorithm, simulated annealing and migrating birds optimization algorithms are developed and customized. We provide computational experiments both on real-world and synthetic data to empirically assess their performance. The results of the algorithms are compared with exact solutions on small instances. The comparison results present that our algorithms finds near-optimal solutions in reasonable execution times. Furthermore, the results show that the proposed versions of the aforementioned algorithms can be applicable to similar problems.

1. Introduction

One of the important topics in operations research and mathematics is finding the shortest path under certain constraints. This topic is mostly referred to as path planning or constrained shortest path problem. The problem of minimizing the time for data to reach destination subject to a given total delay limit in the telecommunications industry (Kuipers, Korkmaz, Krunz, & Mieghem, 2004), the problem of finding the path for a military aircraft with minimum probability of being detected by enemy radar subject to fuel constraints (Zabarankin, Uryasev, & Pardalos, 2002), and the problem of approximating a curve with maximum number of breakpoints subject to storage constraints in computer graphics (Dahl & Realfsen, 1997) are some of the constrained shortest path problems observed in real life. These problems are mostly NP-Complete problems for which applying exact solution methods is not reasonable on moderate or large instances. In this case, heuristic algorithms are usually developed. In the literature, there is also a class of heuristic algorithms which can be used to solve a large class of problems either directly or with minor modifications hence getting the name metaheuristics.

The metaheuristics often generate good solutions in reasonable times. So far many metaheuristics are proposed by researchers. Genetic algorithms, simulated annealing, tabu search, ant system are some of the widely used metaheuristics in the literature (Holland, 1975; Kirkpatrick, Gelatt, & Vecchi, 1983; Glover, 1986; Dorigo, 1992). On the other hand, artificial bee colony, migrating birds optimization, differential evolution are examples of other competitive metaheuristics proposed recently (Karaboga & Basturk, 2007; Duman, Uysal, & Alkaya, 2012; Storn & Price, 1997). As their names imply, the metaheuristics are mostly nature inspired. In the literature, there are some studies that apply metaheuristics to solve the path planning algorithms (Latourell, Wallet, & Copeland, 1998; Lee, 1995; Royset, Carlyle, & Wood, 2009).

In this study, we tackle a path planning problem and design tailor-made metaheuristics for solving the problem. Specifically, the undertaken problem is called obstacle neutralization problem (ONP) wherein an agent needs to safely and swiftly navigate from a given source location to a destination through an arrangement of disc-shaped obstacles in the plane. In the ONP, the agent has a neutralization capability. After neutralizing an obstacle, agent can enter this area and cost of neutralization is added to its traversal length. But neutralization capability is limited, say by K, due to payload capacity of the agent. ONP is closely related to the problems undertaken in real world applications in diverse fields such as telecommunications routing (Kuipers et al., 2004), curve approximations (Dahl & Realfsen, 1997), scheduling and minimum-risk routing of military vehicles and aircraft (Zabarankin

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et al., 2002). Therefore, the techniques developed in this study may also be applied to other application domains.

Mathematically, ONP instance is a tuple $(s, t, \mathcal{A}, c, K)$, where s is start point and t is terminal point in $\mathbb{R}^2$, $\mathcal{A}$ is a finite set of open discs in $\mathbb{R}^2$, c is a cost function $\mathbb{R}_{\geqslant 0}$, and K is a given constant in $\mathbb{R}_{\geqslant 0}$. In this problem we have an agent that wants to go from s to t. This agent cannot enter the discs unless he/she has an option to neutralize discs that can be considered as obstacle or threat like mine. The agent has neutralization capability that is limited with K number of discs where $K \leqslant |\mathcal{A}|$. When a disc is neutralized, its neutralization cost is added to traversal length of the path. In this problem our aim is taking the agent from s to t safely using the shortest path.

There is a simple example for ONP in Fig. 1. In this figure, each disc has radius of 5 and neutralization cost of 1. As seen in figure, when our agent has $K = 0$ neutralization, he/she chooses red (solid) path. Similarly, when $K = 1, 2, 3$ green (dotted), blue (dashed), and black (bold solid) paths are our optimum paths.

To our knowledge, the ONP is studied in Alkaya, Aksakalli, and Periebe (2014), Alkaya and Oz (2014) and Algin, Alkaya, Aksakalli, and Oz (2013). In Alkaya et al. (2014) the authors develop a heuristic for solving the ONP. On the other hand, in Alkaya and Oz (2014) the authors develop an efficient exact method for solving small and moderate sized graphs. However, both of the proposed algorithms are based on the assumption that every disc has the same radius and same neutralization cost. In this paper, that constraint is released and we provide solution methods that can be applicable for more realistic scenarios. In Algin et al. (2013) the authors develop an ant system algorithm for the ONP. However, in their study they just present the algorithm and the results of the computational experiments without any other metaheuristic comparison.

In this study, our contribution is three-fold: (1) we present metaheuristic algorithms that can solve ONP instances having various radii and neutralization cost, (2) our GA, SA and MBO algorithms designed for ONP outperform AS which was developed for ONP in a former study, (3) we show that the proposed metaheuristics present very close results on small and moderate sized graphs and therefore can be used on large graphs.

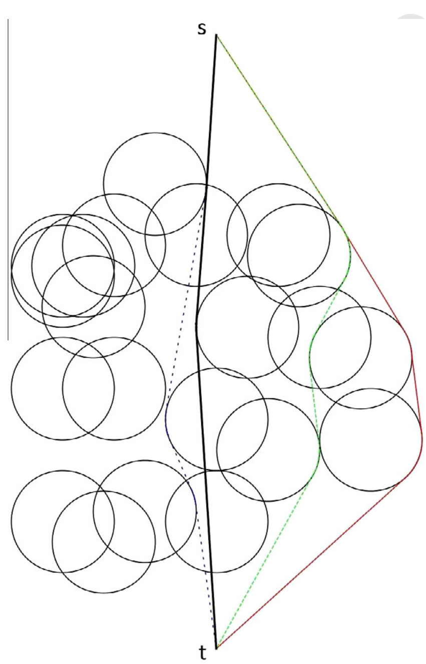

Fig. 1. An example to the obstacle neutralization problem and optimal paths for $K = 0, 1, 2$ and 3.

This manuscript is organized as follows. In Section 2, literature survey on ONP and related problems are given and the metaheuristics used in this study are explained. Section 3 explains how these metaheuristics are customized for demonstrating their best performance on the ONP. Section 4 reports the results of extensive computational experiments which are conducted with real and synthetic data. Section 5 concludes the paper with concluding remarks and some future work.

2. Literature survey

In this section, we firstly provide some background about the studies carried out solely on ONP and then studies carried out on related problems. Thereafter, brief definitions of the ant system, genetic algorithm, simulated annealing and migrating birds optimization are given.

2.1. ONP and related problems

In this subsection, we firstly present the studies carried out on ONP and give the contributions of this study in comparative manner. Then we make a survey on the studies related with ONP because the techniques developed in this study may also be applied to them.

2.1.1. Previous work on ONP

In the literature, ONP is defined in Alkaya et al. (2014) where the authors propose a heuristic for solving the ONP. The proposed algorithm is based on the following simple idea: find the largest penalty term $\alpha^* \geqslant 1$ such that the unconstrained shortest path (i.e., the path without any neutralization limits) with Euclidean length of disc-intersecting edges augmented by $(\alpha^* C)/2$ requires the highest number of neutralizations without exceeding K, hence the name penalty search algorithm (PSA). This is the path returned by PSA and it clearly satisfies the neutralization limit constraint. The search for the penalty term is found by a straightforward bisection method. They present special cases where their algorithm is provably optimal. However, the PSA works correctly under the assumptions of (1) equal radii of the discs, and (2) equal neutralization cost of the discs which may not be realistic in many cases.

In another study on ONP, an exact algorithm is proposed (Alkaya & Oz, 2014). The exact algorithm consists of two phases. In the first phase an upper bound to the problem is obtained by using the PSA algorithm. In the second phase, if there is a gap from optimal solution, starting from the bound obtained from phase I, a kth shortest path algorithm is exploited to find the optimal solution. The performance of the exact algorithm is tested on both grid and continuous graphs where it works very fast on small and moderate sized graphs. However, since it is based on the PSA it requires the same assumptions that PSA has.

In another study, an ant system algorithm for the ONP is developed (Algin et al., 2013). In their proposed algorithm, the state transition rule makes use of certain problem-specific information to guide the ants. They show how the parameters of the algorithm can be fine-tuned for enhanced performance and they present limited computational experiments including a real-world naval minefield dataset. However, in their study they just present the algorithm and the results of the computational experiments without any other metaheuristic comparison.

Summarizing the shortages of the state-of-the-art studies on ONP, we can easily say that: (1) PSA and exact method works correctly under the assumptions of equal radii of the discs, and equal neutralization cost of the discs which may not be realistic in many

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