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Applying the MOVNS (multi-objective variable neighborhood search) algorithm to solve the path planning problem in mobile robotics

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ABSTRACT

Mobile robots must calculate the appropriate navigation path before starting to move to its destination. This calculation is known as the *Path Planning* (PP) problem. The PP problem is one of the most researched topics in mobile robotics. Taking into account that the PP problem is an NP-hard problem, *Multi-Objective Evolutionary Algorithms* (MOEAs) are good candidates to solve this problem. In this work, a new multi-objective evolutionary approach based on the Variable Neighborhood Search (MOVNS) is proposed to solve the PP problem. To the best of our knowledge, this is the first time that MOVNS is proposed to solve the path planning of mobile robots. The proposed MOVNS handles three different objectives in order to obtain accurate and efficient paths. These objectives are: the *path safety*, the *path length*, and the *path smoothness* (related to the energy consumption). Furthermore, in order to test the proposed MOEA, we have used eight realistic scenarios for the paths calculation. On the other hand, we also compared our proposal with other approaches of the state of the art, showing the advantages of MOVNS. In particular, in order to evaluate the obtained results we applied different quality metrics. Moreover, to demonstrate the statistical robustness of the obtained results we also performed a statistical analysis. Finally, the study shows that the proposed MOVNS is a good alternative to solve the PP problem, producing good paths with less length, more safety, and more smooth movements. We think this is an important contribution to the mobile robotics, and therefore, to the field of expert and intelligent systems.

1. Introduction

Nowadays, and due to the great advancements of science and, in particular, technology it is easier to find machines which work in an autonomous and intelligent way. These machines are known as robots. Robots are currently used in a wide range of sectors ranging from the industrial or medical to the social sector. At the beginning, these special machines carried out dangerous, dirty or simply precision tasks; but nowadays, for example, robots can carry out the house tasks while humans are working or take care of the elderly when they are alone. Regarding robots, some of them are equipped with a locomotion system that allows them to navigate through a specific environment. These robots are known as *Mobile robots*. In the robot navigation, the main problem is to calculate a feasible path that allows a robot to move from a starting point to a target point of the environment. This problem is one of the most researched topics in robotics and it is known as *Path Planning* (PP) problem (Shih, Chang, & Chen, 2013).

In this sense, several approaches tackling the PP problem have been proposed. The main disadvantage of these approaches is that most of them are only focused on a single objective, normally minimizing the path length (LaValle, 2006). However, from our point of view, in the case of PP, in order to obtain accurate solutions, it is essential to handle several objectives simultaneously. Specifically, three fundamental objectives can be taken into account: the *path safety*, the *path length*, and the *path smoothness*. With respect to the *path safety*, it is related to the objects of the environment presented in the path. The paths containing fewer objects will be the best (safest). The *path length* objective is focused on obtaining paths as short as possible. This objective is mainly related to the robot operation time since a shorter path will be traveled in less time. Finally, it is important to highlight that robots do not have an infinite energy source (usually batteries are used). The last objective, the *path smoothness*, has as a goal to minimize the number of bends of the path. This objective is directly related to the energy consumption, due to the number and magnitude of turns influence on the consumed energy (Ahmed & Deb, 2013; Jun & Qingbao, 2010). Thus, a path in which the robot has to turn minimally will involve less energy consumption.

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Path Planning is an NP-hard optimization problem (Davoodi, Panahi, Mohades, & Hashemi, 2013) and for this reason it can be tackled by using *Multi-Objective Evolutionary Algorithms* (MOEAs).

In this manuscript, we present an efficient multi-objective version of the *Variable Neighborhood Search* (VNS) Algorithm (Mladenović & Hansen, 1997), a metaheuristic method for solving global optimization problems. Unlike many previous works, we tackle the PP problem in a multi-objective manner, applying a MOEA not previously used, and using realistic maps for the calculation of the paths. These are some important contributions of our work. For the PP problem, we handle the three essential objectives explained above, that is, the *path safety*, the *path length*, and the *path smoothness* (directly related to the energy consumption). This is also important because many previous works use less objectives or are not aware of the energy consumption. Another important contribution of our work is that we developed our own specific evolutionary operators to solve PP.

Due to NSGA-II (Non-dominated Sorting Genetic Algorithm II) (Deb, Pratap, Agarwal, & Meyarivan, 2002) is the MOEA mainly used by other authors who tackled the same problem (with the same objectives) in a multi-objective manner, we used this algorithm as a reference, comparing the results of MOVNS with several implementations of NSGA-II proposed by other authors. This comparison is based on a complete statistical study, with eight scenarios and 31 independent repetitions per experiment.

The rest of the paper is organized as follows. The related work can be found in Section 2. In Section 3 the environment modeling, the path encoding, and the objectives considered in order to solve the PP problem are clearly explained. The evolutionary operators, mechanism to improve the initial population of MOEAs, and the considered MOEAs are explained in Section 4. In Section 5, the methodology used to test MOEAs, that is; the datasets (scenarios), the parameters configuration, and the metrics used are presented. To finish, the results, comparisons with the state of the art, and conclusions are discussed and analyzed in Sections 6 and 7.

2. Related work

In recent years, several studies have been proposed in which MOEAs are applied to tackle the PP problem. Despite of this, some of these works really handle a single objective (EAs). For example, in Geetha, Chitra, and Jayalakshmi (2011), Guo, Wang, and Tian (2009), Hao and Qin (2011), Masehian and Sedighizadeh (2010a), Masehian and Sedighizadeh (2010b), Masehian and Sedighizadeh (2010c), and Krishnan, Paw, and Kiong (2009) the authors use single-objective optimization although in the paper titles they indicate that multiple objectives are used. On the other hand, almost all the real MOEAs applied to the PP problem used the popular NSGA-II algorithm. In Wei and Liu (2010), J.-H. Wei and J.-S. Liu presented an NSGA-II which manages only two objectives. In particular, the algorithm optimizes the path length and the path curvature. In the same way, (Ferariu & Cimpanu, 2014a; 2014b) also proposed a multi-objective genetic algorithm (combined with Dijkstra's algorithm) in order to optimize two objectives: the path length and the total steering angle. Ahmed and Deb (2011), Chang and Liu (2009), and Davoodi et al. (2013) proposed different variants of NSGA-II which also use two objectives: the path length and the path safety (referred to the obstacles), but ignoring the energy consumption. Other works in which the authors used these same objectives, also without taking into account the energy consumption, can be found in Salmanpour, Monfared, and Omranpour (2016), Gong, Zhang, and Zhang (2011), Geng, Gong, and Zhang (2013), Wang, Kwok, Liu, and Ha (2009), and Zhang, Gong, and Zhang (2013). On the other hand, N. Sedaghat also applied NSGA-II and proposed a variant of these two previous objectives, in particular she used the path length in combination with the path difficulty to solve the problem in Sedaghat (2011), also ignoring the energy consumption. These studies took into account only two objectives and the MOEA we present in this study uses three objectives to solve the problem (our third objective is the path smoothness, related to the energy consumption). For this reason, we could not compare with their obtained results. Other variants of MOEAs which optimize two different objectives, in this case the path length and the path smoothness, can be found in Mo, Xu, and Tang (2013) and Wang and Zhu (2013).

On the other side, some authors applied MOEAs optimizing three different objectives, for example, Ahmed and Deb (2013) and Jun and Qingbao (2010) used an NSGA-II algorithm that took into account the path length, the path safety, and the path smoothness. These authors optimized the same objectives as we handle in our work. For this reason, we have used these proposals in order to do a fair comparison with the state of the art, showing the goodness of our approach.

The algorithm (MOVNS) proposed in this work is different to the one used in our previous research based on swarm intelligence (Hidalgo-Paniagua, Vega-Rodríguez, Ferruz, & Pavón, 2015; 2016). In fact, to the best of our knowledge, this is the first time that a multi-objective trajectory-based algorithm is used for solving the PP problem.

Lavin (2014) and Lavin (2015) proposed the A∗-PO and D∗-PO algorithms. These algorithms are based on A∗ and D∗ search algorithms with Pareto Optimality. However, he focused on a very different PP problem. In fact, he modeled a planetary exploration rover in a Mars environment. For this reason, the objectives that he optimized were very different to ours. In particular, he used objectives like the average elevation of the path (for obtaining the path that climbs up the least amount of incline) or the solar incidence (to minimize the total angular deviation of sunlight from the rover's rear solar panel).

Finally, Kim and Kim (2009) and Kim, Kim, Choi, and Park (2009) , applied MOEAs to solve the PP problem in a robot soccer system. This robotics environment is very different to our robotics environment. In fact, they used very different objectives. More specifically, they used the following three objectives: path time, heading direction, and posture angle error. Furthermore, none of them takes into account the energy consumption. Again, all of these authors compared their obtained results with the corresponding NSGA-II algorithm.

Taking into account the previous literature review, the main contributions of our present work are:

- We tackle the Path Planning problem, one of the most important topics in mobile robotics, by using a multi-objective metaheuristic algorithm known as MOVNS (Multi-Objective Variable Neighborhood Search). To the best of our knowledge, no other works have tackled the PP problem by using a Multi-Objective Variable Neighborhood Search algorithm.
- Moreover, to the best of our knowledge, this is the first time that a multi-objective trajectory-based algorithm is used to solve the PP problem.
- The proposed MOVNS handles three different objectives in order to obtain accurate and efficient paths: the *path safety*, the *path length*, and the *path smoothness* (related to the energy consumption).
- Unlike other authors, in this work we use realistic maps of the environment. More specifically, eight realistic scenarios are used. These datasets can be downloaded from http://arco.unex.es/mavega/pathplanning.html. Making easy the reproduction of the research and the future comparison with the results of this paper.
- Our work also proposes new evolutionary operators specifically designed for solving the PP problem and improving the paths.