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New potential field method for rough terrain path planning using genetic algorithm for a 6-wheel rover

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HIGHLIGHTS

- Proposed a new potential field method for rough terrain path planning for a rover.
- A gradient function is introduced in the conventional potential field method.
- The gradient function depends on the roll, pitch and yaw angles of the rover.
- Weights of potential field function are optimized by using GA.
- Results prove that the new method is superior to conventional potential field method.

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ABSTRACT

Motion planning of rovers in rough terrains involves two parts of finding a safe path from an initial point to a goal point and also satisfying the path constraints (velocity, wheel torques, etc.) of the rover for traversing the path. In this paper, we propose a new motion planning algorithm on rough terrain for a 6 wheel rover with 10 DOF (degrees of freedom), by introducing a gradient function in the conventional potential field method. The new potential field function proposed consists of an attractive force, repulsive force, tangential force and a gradient force. The gradient force is a function of the roll, pitch and yaw angles of the rover at a particular location on the terrain. The roll, pitch and yaw angles are derived from the kinematic model of the rover. This additional force component ensures that the rover does not go over very high gradients and results in a safe path. Weights are assigned to the various components of the potential field function and the weights are optimized using genetic algorithms to get an optimal path that satisfies the path constraints via a cost function. The kinematic model of the rover is also derived that gives the wheel velocity ratio as it traverses different gradients. Quasi static force analysis ensures stability of the rover and prevents wheel slip. In order to compare different paths, four different objective functions are evaluated each considering energy, wheel slip, traction and length of the path. A comparison is also made between the conventional 2D potential field method and the newly proposed 3D potential field method. Simulation and experimental results show the usefulness of the new method for generating paths in rough terrains.

1. Introduction

Developing autonomous mobile robotic systems capable of exploring other planets and the Moon, is of great interest to researchers. This involves the design of new mobile platforms, terrain map generation, localization, motion planning, manipulation, etc. The development of new motion planning algorithms on rough terrains are aimed at enhancing the exploration capabilities of mobile robotic systems. The path-planning problem for a mobile robot operating on rough terrain with six wheels is far more complex than that of a differential-drive mobile robot operating on a flat terrain with three or four wheels. The path planning techniques proposed by earlier researchers for mobile robot operating on flat terrain may not be directly applicable on rough terrain as the terrain cannot be simply classified into obstacles and free path. Also, the mobile robot may be designed to go over rough surface without toppling over, and hence obstacle avoidance algorithms are not applicable. In the case of rough terrain the terrain gradients have to be considered inside the path planning algorithm to get the best paths.

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Motion planning for a 10 DOF mobile rover in 3D terrain has significant differences with the traditional motion planning of mobile robots and arm manipulators. Mobile rovers have a large number of DOFs that makes their motion planning difficult due to the presence of complex kinematics of the rover, interaction with the terrain and 3D environment. This involves motion planning with differential constraints associated with the equation of motion (velocity, acceleration etc.). As is explained in [1] several researchers have solved this differential constrained problem in two parts by first performing the path/trajectory generation and then satisfying the path/trajectory constraints. As an example, a particular path may be optimal in terms of minimum distance traversed to reach a goal point but the path may not satisfy the mobile robots velocity and acceleration constraints.

Hence, motion planning in 3D involves the two parts: (i) finding a safe path from one point to another avoiding obstacles and (ii) ensuring that the rover can actually traverse the path satisfying its own constraints of velocity, acceleration, energy, etc. Part (i) is performed by the new potential field function with an added gradient force and part (ii) is ensured by optimizing the weights of the potential field function by minimizing a cost function that considers different rover constraints. In this paper, we present a new potential field method for rough terrain path planning considering geometric and physical properties of the terrain and the rover. A new potential field algorithm is proposed that consists of an attractive force, repulsive force, tangential force and a gradient force. The attractive force is applied to the desired goal, the repulsive force to the obstacles (high un-traversable gradients), a tangential force to avoid traps (concave obstacles) and a gradient force. The gradient force is a function of the roll, pitch and yaw of the rover, that is derived using the kinematic model of the rover depending on its location on the terrain. Different weights are assigned to the four components of the potential field function and they are optimized using genetic algorithms. This ensures that the generated paths also satisfy the path constraints of the rover for successfully traversing the path.

This paper is organized as follows. The review of the previous work is presented in Section 2. Section 3 describes the kinematic analysis of the rover. Section 4 describes the proposed rough terrain motion planning algorithm. Different objective functions are compared in Section 5 to get the best path. Section 6 presents the simulation results obtained by applying the proposed method on different terrains and Section 7 presents the experimental results. Section 8 presents the conclusions.

2. Related work

Muir and Neumann [2] presented kinematic modelling of the rover for 2-dimensional terrain. They have developed matrix transformation algebra to derive the equations of motion of OMRs (Ordinary Mobile Robots). Tarokh et al. [3] describe a method for kinematic modelling of the rocky Mars rover. Tarokh and McDermott [4] proposed a methodology for developing a complete kinematics model of a general All-Terrain Rover (ATR) and its interaction with the terrain. Seegmiller and Kelly [5] presented a simple algorithmic method to construct 3D kinematic models for any WMR (Wheeled Mobile Robot) configuration.

There exist many different path planning methods that work well for mobile robots in plane terrain. The cell decomposition methods [6–8] in which the configuration space is divided into smaller regions called cells, then a connectivity graph is constructed according to the adjacency relationships between the cells. This method provides a path but is suitable only for lower dimensional C-spaces. In general, cell-decomposition methods are computationally expensive and are not recommended to use for high dimensional configuration spaces [9]. There are various types of roadmap methods, including visibility graph [10], Voronoi diagram [11] and the silhouette [9]. These guarantee in finding path but the approaches are suitable for planar terrain. Probabilistic Roadmap Method (PRM) [12,13] has proved to be successful in finding feasible paths. However, the two limitations of unnecessary collision checks and narrow passage problem raised the need for further research. An evolutionary algorithm [14–17], genetic algorithm [18,19], fuzzy logic [20] concepts have been shown to be effective for planar terrain but do not extend well to rough terrain.

The artificial potential field method was first proposed by Khatib [21] for manipulators. Koren and Borenstein [22] described the virtual force field concept and identified the limitations of local minima, non-smooth movement, oscillations due to obstacles, oscillations in narrow passages. Later researchers proposed a new potential field to handle local minima [23–26]. An improved wall following method for escaping local minima in artificial potential field was proposed by Zhu, Zhang, and Song [27]. A new harmonic potential function is proposed by [28]. Jia and Wang [29] proposed a modified potential function to overcome the problem of goals non-reachable with obstacles nearby (GNRON). The new attractive function decreases the potential around goals evidently to eliminate the problem. Velagic et al. [30] proposed a modified potential field method with fuzzy logic to pull the robot out of the local minima and attention is paid to detect the robot's trapped state and its avoidance. Yin and Yin [31] defined new attractive and repulsive potential function with respect to the relative position, velocity, and acceleration among the robot, the goal and the obstacles, to make the robot plan its motion not only with right positions, but also with suitable velocities. The exponential decrease of potential around the obstacle can cause the paths to be very close to obstacles, raising safety issues. To tackle this situation, a virtual obstacle concept for obstacle avoidance was proposed by Shehata and Schlattmann [32]. Shehata and Schlattmann [33] proposed a method to optimize the robot size factor and the multiplying factor of repulsive potential to maintain safety margin around the obstacles by the use of NSGA II. Li et al. [34] proposed a method of obstacle avoiding trajectory using potential grid method to avoid recursive U-shaped, unstructured, cluttered, and maze-like environment. All the methods described above are based on a binary representation of the terrain in which regions of the terrain are considered either occupied or free cells.

Iagnemma et al. [35] presented an overview of physics-based rover and terrain modelling techniques. A rough terrain motion planning method is presented in [36] that considered range data and computes the path using A* algorithm based on user-defined performance index (terrain roughness, robot turning cost and path length). Tarokh [37] developed a hybrid intelligent path planning for articulated rover in rough terrain. The algorithm first takes images of the natural terrain, and then differentiated background from the rock by calculating the optimum threshold value from the histogram of natural terrain. In this case, the author has considered the terrain as obstacle or free space. A path planning method considering gradient calculation and the instability of attitude manoeuvres on rough terrain is proposed in [38].

3. Rover kinematics

The rocker-bogie type rover consists of six wheels, a central body, a diferential, and rocker and bogie links. The 6-wheel system was designed to ensure contact of all the six wheels with the ground even while moving on highly uneven terrains. Fig. 1(a) and (b) show schematic diagram of the front view and the side view of the rover with the dimension. The experimental rover on the terrain is depicted in Fig. 1(c). Each of the wheels has an independent driving motor to maximize the traction capability of the rover. It