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# Hybrid Gravity Gradient Inversion-PSO algorithm for Motion Planning of Mobile Robots

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## Abstract

Motion planning is a common task required to be fulfilled by robots. A novel strategy combining particle swarm optimization and gravity gradient inversion algorithm is proposed for motion planning of mobile robots. Particle Swarm Optimization (PSO) is employed to do motion planning and fitness function in PSO is built based on gravity gradient inversion algorithm. The relative distance and orientation between each particle and the center of an obstacle is calculated by gravity gradient inversion algorithm, then, a fitness function is built based on the distance and orientation. The proposed strategy is validated by the simulation and experiment results.

**Keywords:** Particle swarm optimization; Gravity gradient inversion Algorithm; Motion planning.

## Introduction

Motion planning and obstacle avoidance are two related areas of research with broad commercial and military applications. How to do motion planning and obstacle avoidance effectively is still a major challenge in autonomous navigation field nowadays. Over past decades, object detection algorithms based on gravity gradient and magnetic anomaly have been researched widely [1-3]. In the field of underwater object detection based on gravity gradient tensor, Lin Wu [1] used gravity gradient inversion method to detect abnormal underwater objects in underwater environment. Zu Yan [3] presented a novel method for underwater object detection based on the gravity gradient differential and the gravity gradient differential ratio caused by the relative motion between the AUV and the underwater object.

Particle Swarm Optimization (PSO) is an evolutionary algorithm based on a number of particles that search for the global minimum of a potential function [4,5]. Each particle can adjust its position according to previously found optimal values and a random parameter [5]. An online multi-robot path planning algorithm is proposed and it combines the benefits of particle swarm optimization and agoraphilic algorithms [5]. A particle swarm optimization algorithm combined with probabilistic roadmap method is employed to do path planning and obstacle avoidance [6,7]. A method for developing feasible paths through complicated environments using a baseline smooth path based on cubic splines founded by PSO algorithm is proposed for autonomous robot path planning [8]. Dynamic Distributed Particle Swarm Optimization (D$^2$PSO) algorithm is employed to do multi robots path planning considering collision risks [9-11].

In this paper, gravity gradient inversion algorithm is combined with particle swarm optimization to do motion planning and obstacle avoidance for mobile robots, the fitness function of particle swarm optimization (PSO) algorithm is built based on gravity gradient inversion method.

This paper is organized as follows. In the 'System overview' section, system architecture of this platform is introduced, in the next section, motion planning algorithm based on joint gravity gradient inversion and particle swarm optimization is introduced and analyzed. In subsequent section, simulation results are discussed. Conclusions are summarized in the last section.

## Methodology

### System overview

In this paper, particle swarm optimization algorithm and gravity gradient inversion algorithm are combined to realize motion planning and obstacle avoidance. The proposed algorithm in this paper can find a shortest and collision-free path for mobile robots.

A gradiometer installed on each particle in particle swarm optimization (PSO) can detect gravity gradient anomaly caused by an obstacle, then, gravity gradient inversion algorithm is employed to calculate relative distance and orientation between each particle and the centre of an obstacle. The relative distance and orientation are employed into a fitness function in particle swarm optimization (PSO) algorithm to finish motion planning for mobile robots. The flow chart is shown in Figure 1.

### Hybrid gravity gradient inversion with particle swarm optimization algorithm

The proposed PSO algorithm is to design a proper fitness function based on the gravity gradient inversion algorithm. The fitness function is based on relative distance and orientation between each particle and centers of obstacles. Assuming a fact that obstacles can cause gravity gradient anomalies on each particle, the gravity gradient inversion algorithm is employed to calculate the distance and orientation. According to the distance and orientation, fitness function is proposed and combined into PSO algorithm to finish motion planning (Figure 2).

Assuming a fact that each particle can detect gravity gradient anomalies caused by obstacles and the relative distance between each particle and an obstacle can be calculated by gravity gradient inversion algorithm. Thus, objective function based on the relative distance is defined as:

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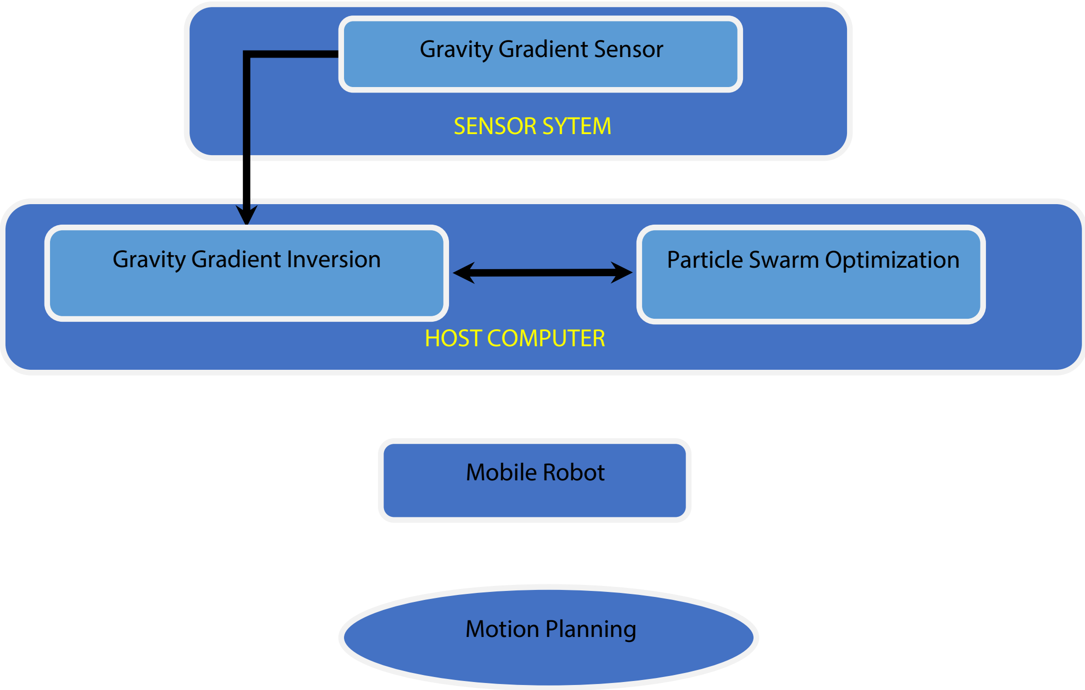


**Figure 1:** Flow-Chart of motion planning algorithm based on PSO combined with gravity gradient inversion method.

```
Procedure PSO Algorithm
  While maximum iterations is not attained do
      For each particle do
          Initialize particle
      End
      For each particle do
              Calculate the fitness value based on Gravity Gradient
                   Inversion Method
        If fitness value is better than best fitness value p_lbest_j^(i-1)
        Then Set current value as the new p_lbest_j^(i-1)
        End
      End
      For each particle do
        Find the particle with the best fitness p_gbest_j^i
        Update particle velocity according to PSO velocity equation
        Update particle position according to PSO position equation
      End
  End
```

**Figure 2:** Pseudo-code of the basic hybrid PSO-gravity gradient inversion algorithm.

$$\begin{cases} d_j^i = \sqrt[3]{\dfrac{GM}{\Gamma_{particle_j^i(xx)} + \Gamma_{particle_j^i(yy)}} \left(1 - \dfrac{3}{\left(\dfrac{\Gamma_{particle_j^i(xy)}}{\Gamma_{particle_j^i(yz)}}\right)^2 + \left(\dfrac{\Gamma_{particle_j^i(xy)}}{\Gamma_{particle_j^i(xz)}}\right)^2 + 1}\right)} \\ d_j^i = \sqrt{\left(x_{particle_j^i} - x_{obstacle}\right)^2 + \left(y_{particle_j^i} - y_{obstacle}\right)^2 + \left(z_{particle_j^i} - z_{obstacle}\right)^2} \\ F_{1j}^i = \max\left(\dfrac{d_j^i}{r_{obstacle}^i}\right) \end{cases} \quad (1)$$

is designed as a fitness function to denote the relative distance between a particle in PSO and an obstacle. If $r_{obstacle}^i$ is bigger than $d_j^i$, it means that a particle is approaching closely to an obstacle, on the contrary, if $r_{obstacle}^i$ is smaller than $d_j^i$, it means that a particle is moving away from an obstacle. In this paper, the maximum of $F_{1j}^i$ is employed to find out a max distance between a particle and obstacles to realize obstacle avoidance. Where $d_j^i$ denotes the relative distance between a particle in PSO algorithm and an obstacle in environment. $x_{particle^i_j}$ , $y_{particle^i_j}$ and $z_{particle^i_j}$ denote coordinates of the $j^{th}$ particle at iteration *i*. $\Gamma_{particle^i_j(x,y,z)}$ describes gravity gradient anomalies caused by an obstacle and the anomalies can be detected by a gradiometer installed on the $j^{th}$ particle. $x_{obstacle}$ , $y_{obstacle}$ and $z_{obstacle}$ are coordinates of an obstacle. $r^i_{obstacle}$ denotes radius of the $i^{th}$ obstacle. G denotes gravitational constant and M is the mass of an obstacle.

$$\begin{cases} \theta^i_j = \dfrac{\left(y_{particle^i_j} - y_{obstacle\,j}\right)}{\sqrt{\left(x_{particle^i_j} - x_{obstacle\,j}\right)^2 + \left(y_{particle^i_j} - y_{obstacle\,j}\right)^2 + \left(z_{particle^i_j} - z_{obstacle\,j}\right)^2}} \\ \theta^i_j = \arctan\left(\dfrac{\Gamma_{particle^i_j(yz)}}{\Gamma_{particle^i_j(xz)}}\right) \\ F^i_{2\,j} = \max\left(\theta^i_j\right) \end{cases} \quad (2)$$

where, $\theta^i_j$ denotes the relative orientation between a particle in PSO algorithm and an obstacle in environment. $F^i_{2\,j}$ is designed as a fitness function to evaluate the relative orientation between a particle in PSO and an obstacle. In this paper, the maximum of $F^i_{2\,j}$ is calculated to find out a max relative orientation between a particle and obstacles to realize obstacle avoidance. The overall fitness function is obtained by the weighted sum of eqns (1) and (2).

$$\begin{cases} F^i_j = \beta_1 \times F^i_{1\,j} + \beta_2 \times F^i_{2\,j} \\ \beta_1 + \beta_2 = 1 \end{cases} \quad (3)$$

where weights of the fitness function, $\beta_1$ and $\beta_2$ are tuned through extensive try and simulation. In this paper, the best found values $\beta_1$=0.25 and $_2$=0.75.

## Simulation, Results and Discussion

In this simulation, gravity gradient inversion algorithm is combined into particle swarm optimization (PSO) method to realize motion planning for mobile robots. The simulation is based on a gravity gradient reference map whose size is 512 × 512 and the resolution is 25 × 25 m, while the measuring point's elevation is 600 m. The reference map is shown in Figure 3.

In Figure 4(a) and 4(b), when we set the iteration times are 200 times, more particles in PSO show an improved performance in motion planning and obstacle avoidance in the gravity gradient reference map.

If we set more particles and more iterative times shown in Figure 4(c), PSO combined with gravity gradient inversion algorithm shows a better performance in obstacle avoidance compared with the results from Figure 4(d). Thus, PSO combined with gravity gradient inversion algorithm is a good solution to find shortest path efficiently within complex obstacles.

## Conclusion

This paper proposed a novel motion planning approach for mobile robots using gravity gradient inversion algorithm and particle swarm optimization (PSO) algorithm. Specifically, the fitness function in PSO algorithm is designed based on gravity gradient inversion algorithm. A shortest and collision-free path is obtained based on the method proposed in this paper. The simulation clearly demonstrates the efficacy

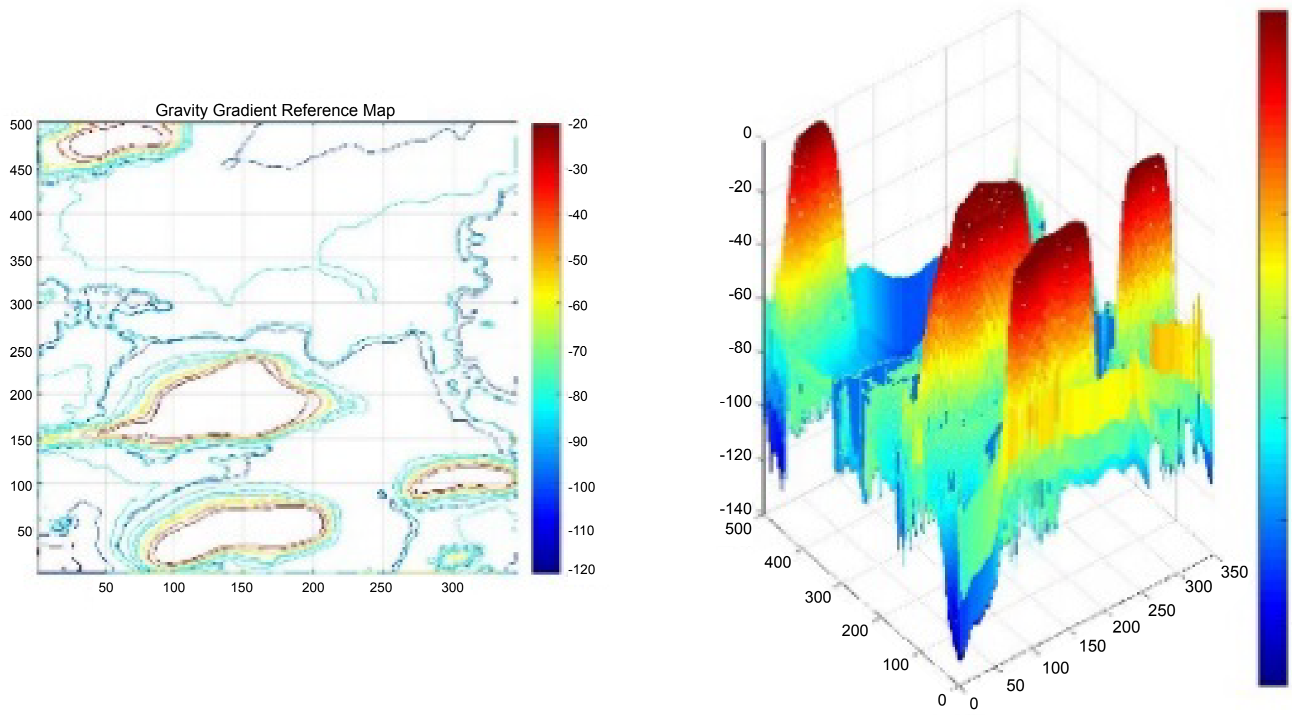


**Figure 3:** Gravity gradient reference map

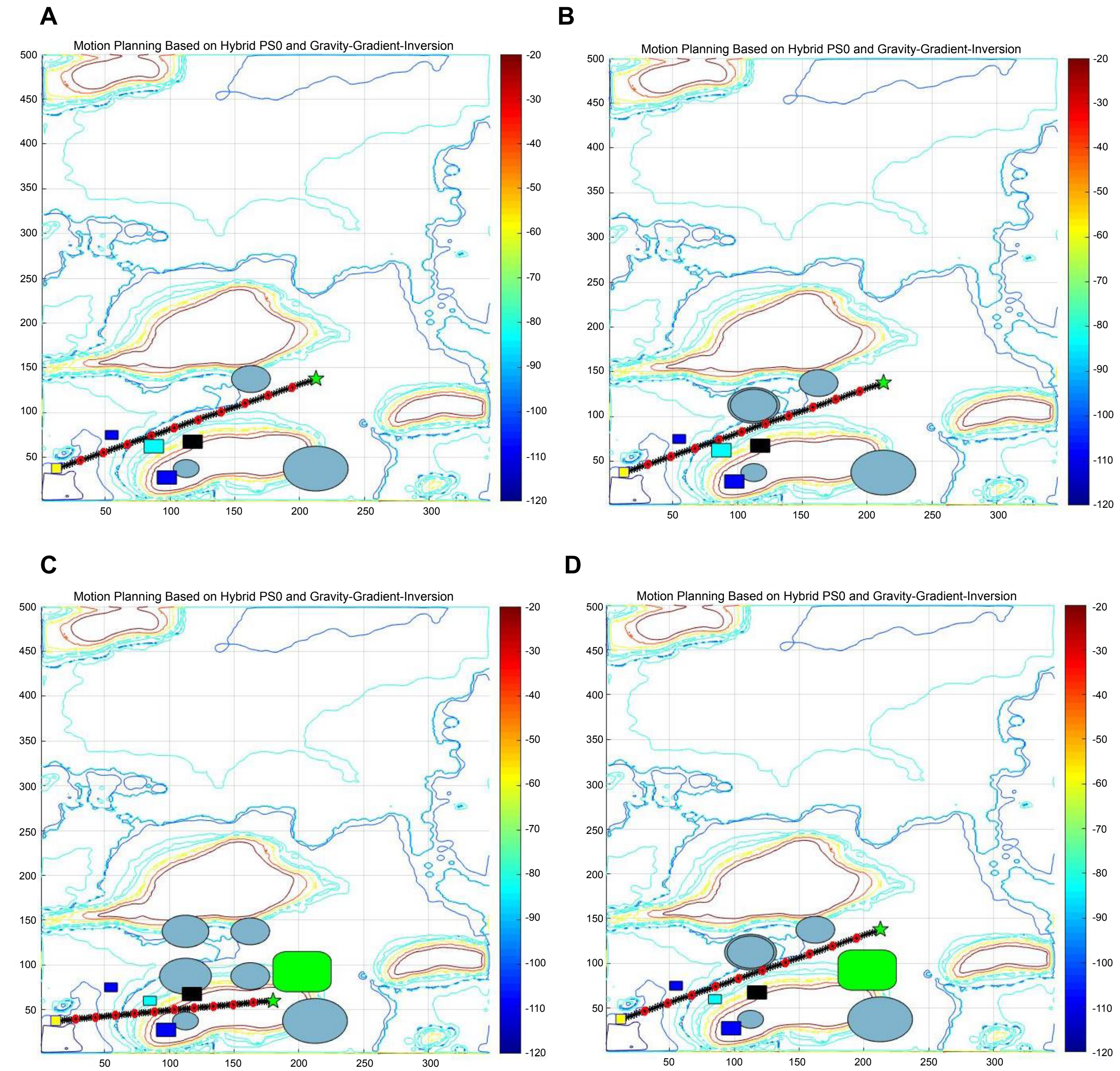


**Figure 4:** Simulation based on hybrid gravity-PSO algorithm. **(a)** 150 particles+200 iteration; **(b)** 300 particles+200 iterations; **(c)** 1000 particles+500 iteration; **(d)** 1000 particles+200 iteration.

of the proposed approach, which successfully achieves very high levels of motion planning and obstacle avoidance.

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