3-D Path Planning using Improved Artificial Potential Field

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***Abstract*—Mobile robots are becoming more and more widely used in industry and life, so the navigation of mobile robots has become an urgent problem to be solved.This project deals with the path planning of mobile robots to avoid static obstacles using improved Artificial Potential Field method. The classical Artificial Potential Field (APF) method consists of assigning an attractive artificial potential field to the destination point that attracts the robot, and a repelling artificial potential field to the obstacles that repel the robot. We use modified APF which redefines the repulsive and attractive potential fields and add correction factors to them to avoid the inherent problems of the classical APF such as the local minima and the inaccessibility of the target.**

***Index Terms*—Path planning, Artificial Potential Field**

I. Introduction

THe idea of a path planning approach is to make the robot move from its starting point towards a destination point, or goal, while avoiding obstacles on its way. There is a lot of work that has already been done in the field of obstacle avoidance and continues to improve however, the real-time path planning to avoid static and dynamic obstacles in the known and unknown environments needs more attention and efficiency. The potential field method is widely used for autonomous mobile robot path planning due to its elegant mathematical analysis and simplicity. It was introduced by Khatib in 1986[1]. The Artificial Potential Field (APF) method assigns to the destination point a virtual potential that increasingly attracts the robot with distance and, to the obstacles, a virtual potential that increasingly repels the robot as it gets closer to them. Globally, the robot moves toward the destination point while avoiding the obstacles along its way. Some studies employ APF to create the potential of road boundaries which allows the vehicle to maintain within its lane on the road, simultaneously allowing a safe distance for any sudden appearing object. However,this algorithm has many drawbacks; the major drawback of this problem is at the local minimum and the inaccessibility of the target when the obstacles are in the vicinity of the target. Significant work has been done to improve and modify the APF method which includes discretising the potential field[7]. An another improvisation was using the hybrid approach which use APF with algorithms like Beetle Antenna Search (BAS)[12].

II. Previous Work

Due to it's simplicity,this method has the potential in a lot of applications like indoor robots,underwater robots, large autonomous ships etc. Therefore,there has been a lot of work done to improve the Artificial Potential Field method. Some of the major work include dicretizing the potential field, Fusion with other algorithms and Regression search. We will these works in detail below.

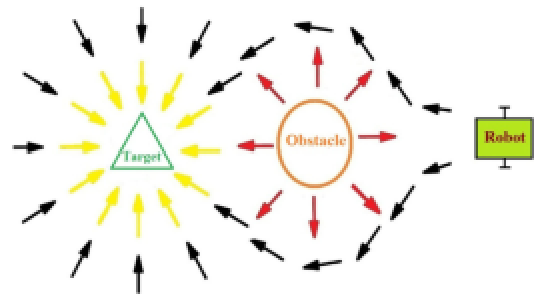

Fig. 1: Artificial Potential Field

1. Discrete Artificial Potential Field

The proposed method takes into account the local minima and GNRON (Goal Not Reachable) by modifying the repulsive forces formula. The DAPF algorithm is capable of finding a collision free path for a mobile robot in static and dynamic environment in discrete configuration space.

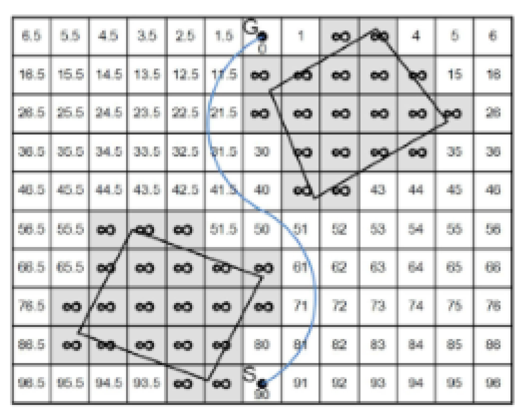

Fig 2: Discrete artificial potential field implementation

2. A* and APF fusion algorithm

This fusion algorithm combines A* algorithm with artificial potential field method both improved and optimized for 3D environment. Firstly, A* algorithm is adopted to plan the preliminary path in the environmental model established by grid method. Finally, this A* algorithm is optimized in the heuristic function according to the 3D environment.

3. Regression Search Method

Due to the planned path by improved APF is not the shortest/approximate shortest trajectory,regression search (RS) method[4] is developed to optimize the planned path. The optimization path is calculated by connecting the sequential points which produced by improved APF.

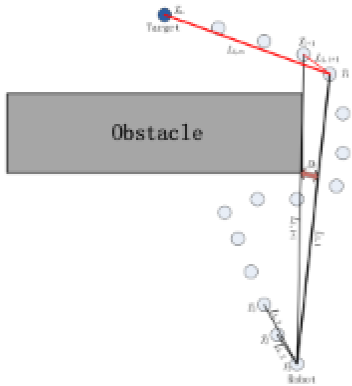

Fig 3: Regression Search Method Implementation

III. Challenges

The challenges identified in the current implementation of our traditional artificial potential field method involves the oscillation issue where the path keeps oscillating close to the target when an obstacle is present there.

To analyse the problem,we implemented the traditional APF in the 2D grid in Python. Each grid was assigned the sum of weights based on the Euclidean distance of agent from the obstacle and the goal. The agent moves to the neighbor with the minimum weight in the grid and the process repeats itself till the goal is reached.

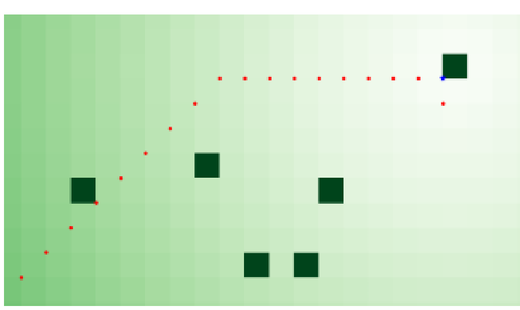

Fig 4: Oscillation in traditional APF method.

In this project we try to address the problem of path planning in the presence of static obstacles by utilising the improved Artificial Potential Method. Dynamic environments necessitate the path planning to be performed in real time with less computational time and faster implementation. The traditional implementation of artificial potential method suffers from the Goal Non Reachable when Obstacles are Nearby (GNRON) problem and the Local Minima problem and hence our focus is on eliminating these problems and improving the efficiency.

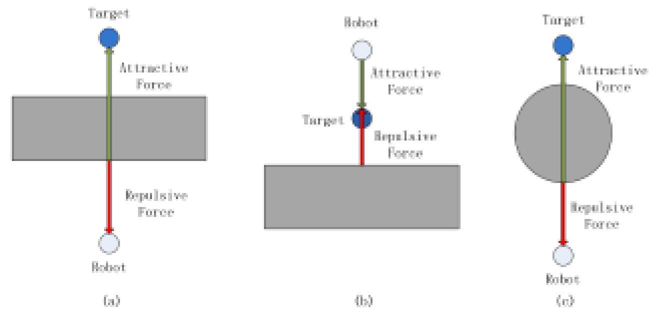

Fig. 5: Local minima

The oscillation condition is defined as one in which the path moves to three cells at the same potential and thus the goal cannot be reached. Thus there is the need to overcome this problem using improved APF.

IV. Methodology

The basic idea of APF method assumes that robot as a point moves in an abstract artificial force field. The artificial field in environment is composed of attractive field of target and repulsive field of obstacles. Attractive field is produce by target and direct to target point, while repulsive field is the synthesis repulsive field of different obstacles and the direction of the synthesis repulsive field is away from obstacles. Therefore, the potential function is the APF of robot which is defined as the resultant of attractive field and repulsive field. Robot controls its movement toward the target point along the direction of APF. Under the method of APF, robot could find a collision-free path by searching the route along the decline direction of potential function. The negative gradient of APF is defined as artificial force which is the steepest descent direction for guiding robot to target point. Attractive force is the negative gradient of attractive field, and repulsive force is the negative gradient of repulsive field. The attractive potential is defined as:

$$U_{att}(X) = \frac{1}{2}K_{att}(X - X_g)^2 \tag{1}$$

The repulsive potential is given by:

$$U_{rep}(X) = \begin{cases} \frac{1}{2}K_{rep}(\frac{1}{X - X_0} - \frac{1}{\rho_0})^2, & X - X_0 \leq \rho_0 \\ 0, & X - X_0 > \rho_0 \end{cases} \tag{3}$$

where

$$\rho_0 = the-largest-impact-distance-of-single-obstacle.$$

However, when rho-goal is very great, the attractive force will become very great too. In other words, when robot is far away target, it is easily leading robot move too close toward the obstacles. Therefore, in the real environment shown in robot has the risk of collision to obstacles when we take account the error of path planning. Thus, the attractive field and attractive force are modified as

$$F_{att}(q) = \begin{cases} -k(q - q_g) & , \|q - q_g\| \leq d \\ -dk\dfrac{(q - q_g)}{\|q - q_g\|} & , \|q - q_g\| \geq d \end{cases}$$

$$F_{rep}(q)=\begin{cases} 0 & ,\rho(q)\geq\rho_0 \\ \eta(\frac{1}{\rho(q)}-\frac{1}{\rho_0})(\frac{1}{\rho^2(q)})\frac{q-q_c}{\|q-q_c\|} & ,\rho(q)\leq\rho_0 \end{cases}$$

Where, d is positive coefficient for attractive field and force

V. Results

For the implementation,the 3-D environment is created in MATLAB using the cylinder obstacles of different heights. The agent will start from the ground and reach the target at the given x,y and z coordinates.

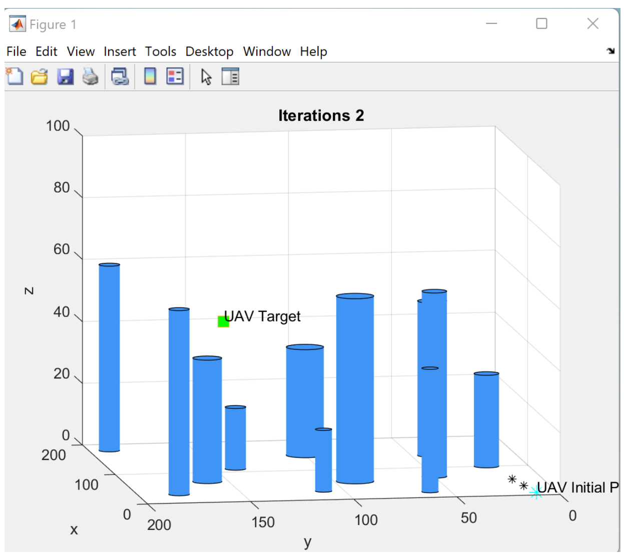

Fig.6 3-D environment for path planning

The improved APF is applied in MATLAB and path is generated in 3-D to reach the goal.As can be seen in the figure, the agent starts from the start position and starts moving towards the goal. The agent only moves in the xy plane while near the obstacles as Fz is zero to prevent the complex movement of the mobile robot. The final path is demonstrated in the figure.

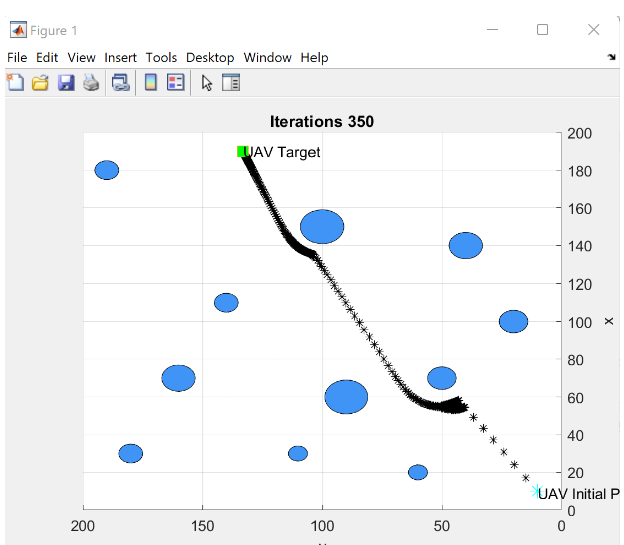

Fig.7 Final path depicted in 2-D

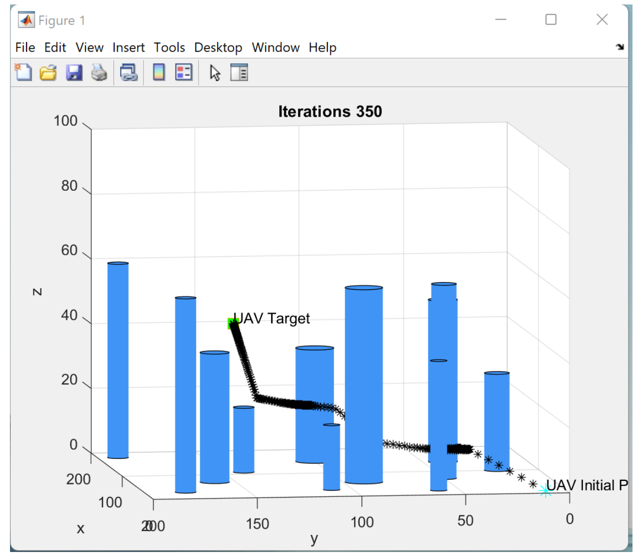

Fig.8 Final path depicted in 3-D

The above figure shows the agent reaching the final position in a 3D environment with the obstacles modelled as cylinders. The quiver plot of the system is shown in the figure below which provides an idea of the attractive and repulsive potential fields generated by the goal and obstacles respectively.

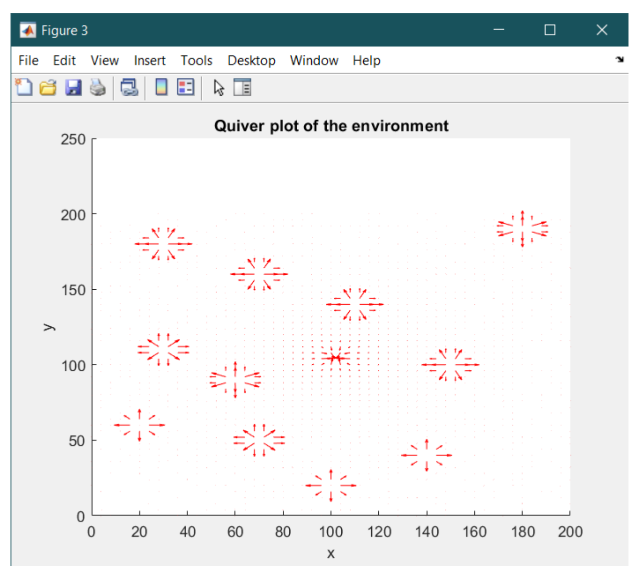

Fig.9 Contour plot

A 3-D mesh graph that provides spikes and downs based on the building positions and goal position are also plotted as shown in figure below.They are only plotted while taking into the account of XY plane of the created environment.

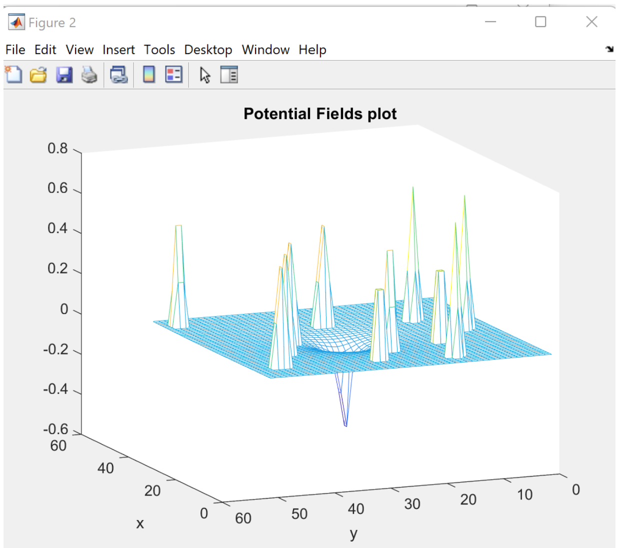

Fig.10 Potential field plot of environment

VI. Conclusion

Path planning problem is one of the most important problems for mobile robots to accomplish given tasks.The artificial potential field method defines the attractive and repulsive forces for the goal and obstacles respectively. While this method is of great usage due to it's simplicity in real-time.However, it has some problems associated with it such as local minima and GNRON. First, we investigated these problems by implementing the traditional artificial potential field method. We analysed and reviewed different methods to overcome the limitations of traditional artificial potential field method. Finally we proposed the improved artificial potential field method. Then we addressed these problems by using the improved version of the Artificial Potential Method. Attractive forces formula is modified such that when the agent is away from the goal by a certain constant distance, it is clipped. The agent was successfully able to reach the goal without getting stuck and oscillations near the goal and thus the proposed improved artificial potential field method has been proven to address the problems of traditional artificial potential field method.

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