# Modified Artificial Potential Field for UAV Formation Generation and Changing

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## Introduction

This paper addresses a formation tracking control issue for multiple Unmanned Aerial Vehicles (UAV) flying through a constrained space. Based on the Formation Potential Field (FPF), a Modified Artificial Potential Field (MAPF) technique is proposed, which guarantees to generate and maintain a given formation while avoiding collisions. Each UAV can be attracted to the target position without further guidance. The technique can deal both static or dynamic obstacles. The technique has two phases. UAVs are gathered around the formation center first during Phase 1, and the formation is then achieved in Phase 2. Furthermore, an obstacle repulsive potential field is introduced into this approach to deal with collision avoidance under environmental constraints. By doing so, discontinuities of the original Formation Potential Field can be avoided, and the stability of formation generation could be enhanced. Simulation results are presented to illustrate the validity of proposed approach.

## Problem Definition

The formation keeping problem of multiple UAVs in a dynamic environment consist of three problems: (i) how to plan, control and generate a given UAVs formation at their initial positions; (ii) moving UAVs as a group in formation from the initial position to the destination; (iii) avoidance of collisions during their flight. The control goal is:

$$\sum_{i=1}^{n} \|\tilde{\boldsymbol{x}}_i(t)\| \le \varepsilon, \qquad \|\boldsymbol{x}_0(t) - \boldsymbol{x}^r(t)\| \le \epsilon$$

where $\varepsilon$ and $\epsilon$ are two small constants; $\tilde{x}_i(t)$ defined as the tracking error of UAV $v_i$ at time $t$. $x_0(t)$ is the location of the virtual leader.

$$\tilde{\boldsymbol{x}}_i(t) = \{\min(\|\boldsymbol{x}_i(t) - \boldsymbol{x}_j^d(t)\|, j = 1, \dots, n)\}$$

$$\boldsymbol{x}_0(t) = \frac{1}{n}\sum_{1}^{n} \boldsymbol{x}_i(t)$$

## Artificial Potential Field

- ***Global Attractive Potential Field***

The main purpose of the global attractive potential field is to gather UAVs into one place.

$$U_i^{ga}(x_i, x^r) = k_{a1} f_{ga}(x_i, x^r)$$

$$f_{ga}(x, x^s) = \frac{1}{2}(x - x^s)^T K (x - x^s)$$

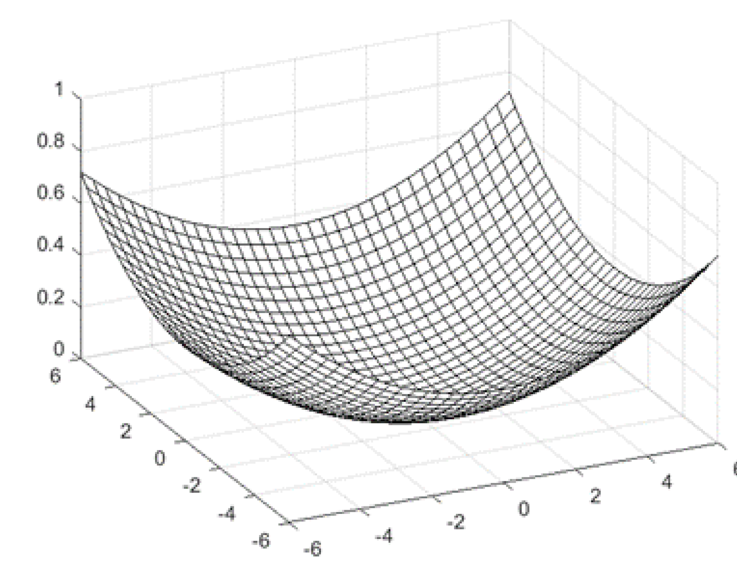

**Figure 1**. Global Attractive Potential Field

- ***Local Repulsive Potential Field***

The function of local repulsive potential is to avoid collisions between two UAVs. Furthermore, it can guide UAVs in a well distributed fashion around the formation center.

$$U_i^{lr}(x_i, x^r) = k_{r1} f_{lr}(x_i, x^r)$$

$$f_{lr}(x, x^s) = \frac{1}{2(x - x^s)^T K (x - x^s)}$$

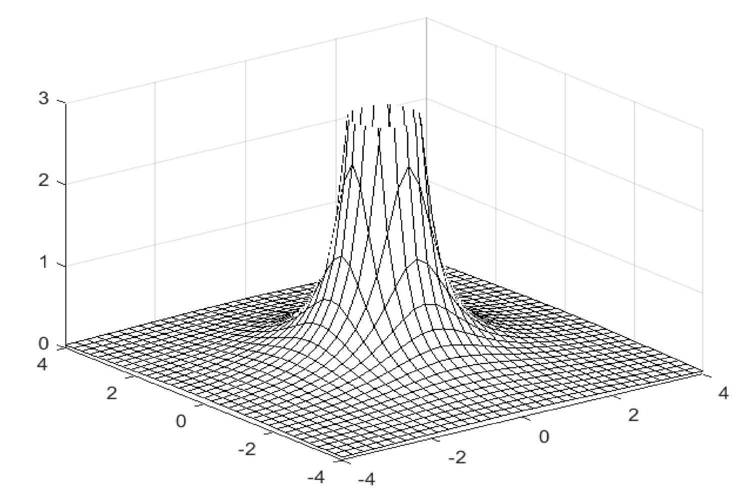

**Figure 2**. Local Repulsive Potential Field

- ***Local Attractive Potential Field***

The local attractive potentials are located in desired formation positions. It attract UAVs into the desired formation position with relatively small affect area.

$$U_i^{la}(x_i, x^d) = 1 + k_{a2} \sum_{j=1}^{N} f_{la}(x_i, x_j^d)$$

$$f_{la}(x, x^s) = -\exp\left[-\frac{1}{2}(x - x^s)^T K (x - x^s)\right]$$

- ***Collision Avoidance with Spatial Constraints***

The repulsive potential field for environment obstacles.

$$U^c(\boldsymbol{x}) = \sum_{r=1}^{R} \iint_{-\infty}^{\infty} \frac{k_{cr}\delta(\|\boldsymbol{x} - \boldsymbol{s} - kP_r(\boldsymbol{s})\|)}{\|\boldsymbol{x} - \boldsymbol{s}\| - s_0} ds_1 ds_2$$

$$P_r(\boldsymbol{s}) = \begin{bmatrix} \dfrac{\partial L_r}{\partial s_2} & -\dfrac{\partial L_r}{\partial s_1} \end{bmatrix}^T$$

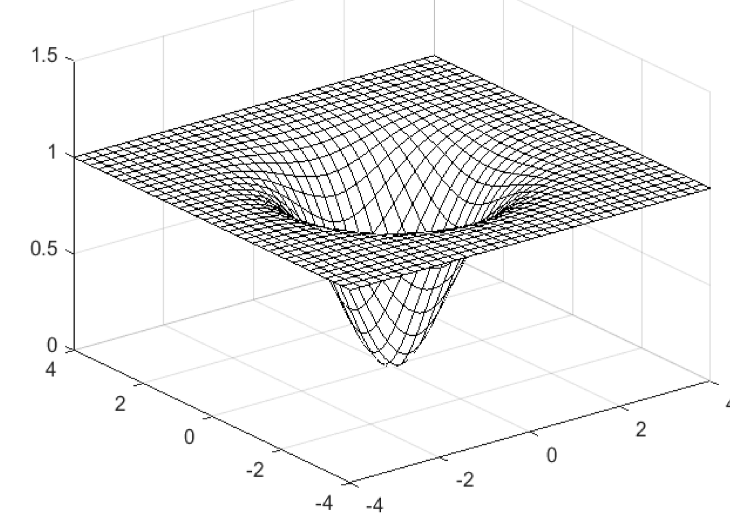

**Figure 3**. Local Repulsive Potential Field

- ***Phased I Potential Field***

By combining one global attractive potential with one local repulsive potential, we obtain the Phase I potential field.

$$U_i^1 = U_i^{ga} + U_i^{lr}$$

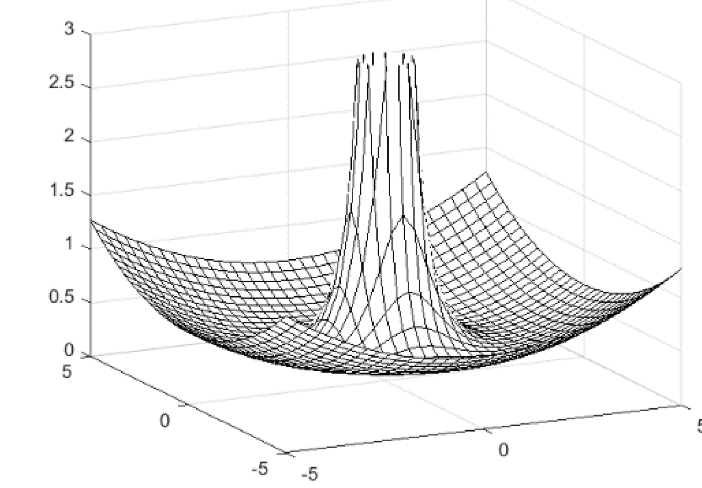

**Figure 4**. Phase I PF

- ***Phased II Potential Field***

The Phase II potential field is constructed with the local attractive potential fields and local repulsive potential fields. For a random UAV, local attractive potentials are located in desired formation positions and centers of local repulsive potentials are at other UAVs' locations.

$$U_i^2 = U_i^{la} + U_i^{lr}$$

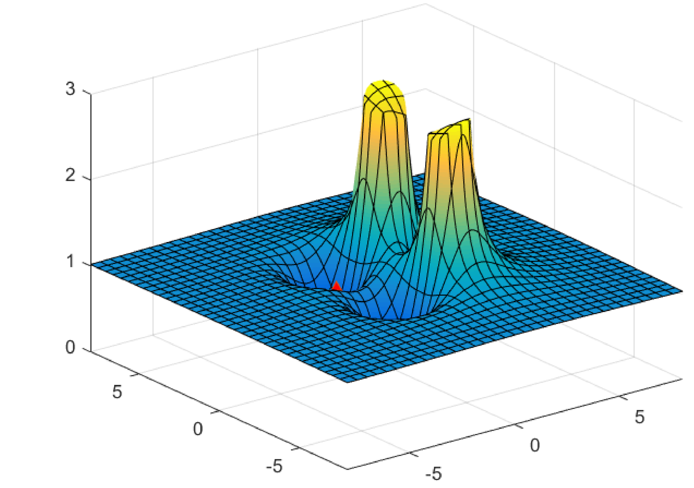

**Figure 5**. Phase II PF

## Simulation Results

The simulation shows when the Formation Potential Field failed to generate a given formation (since UAVs are nor well distributed around the formation center) while MAPF method behave as expected.

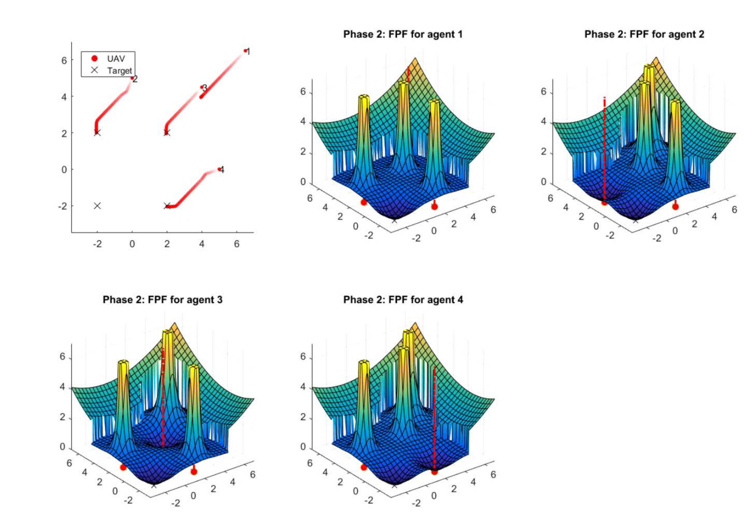

**Figure 6**. FPF Failure Case

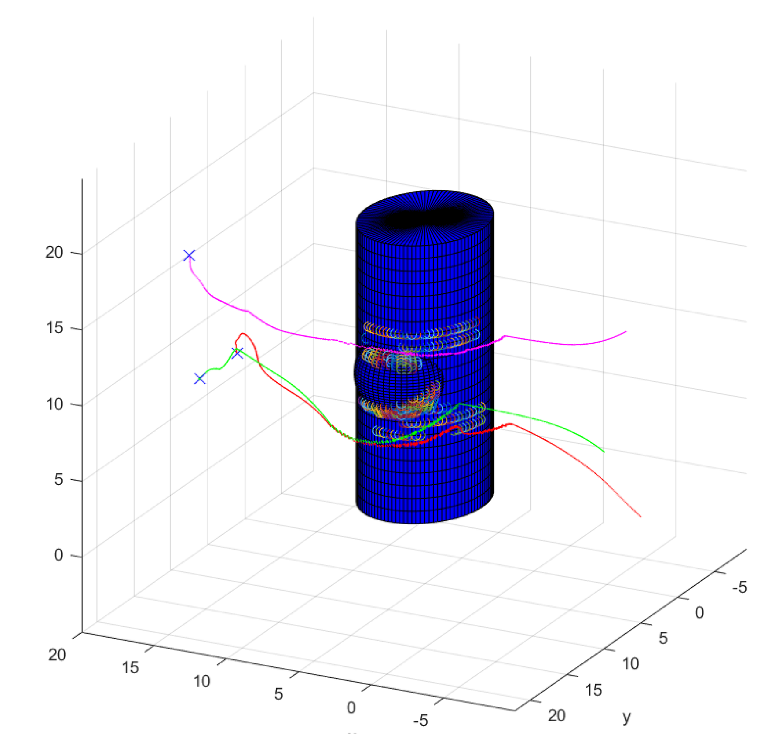

**Figure 8**. MAPF 3D Simu.

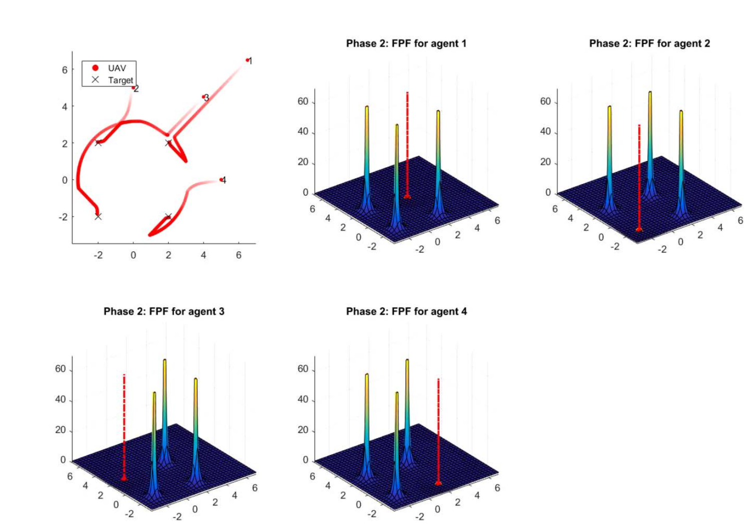

**Figure 7**. MAPF 2D Simu.