A new dynamical attractive and repulsive fractional potential for UAV in 3D dynamical environment

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Summary. In recent years, applications for drones have multiplied, from surveillance, exploration, rescue and transport applications. UAVs are more and more autonomous, therefore real-time trajectory planning is necessary and can be achieved with potential fields. A quick study is proposed to better scale attractive and repulsive forces which has always been problematic when dealing with artificial potential fields. The purpose of this article is to develop a new dynamical fractional potential attractive and repulsive field usable in a dynamical 3D environment by taking into account the obstacle dynamics (position and speed) and theirs dangerousness. This makes it possible to avoid the obstacle in a more robust way, both from a safety point of view and from a trajectory optimization point of view. The potential fields are based on the relative position and speed of the drone in relation to the target for the attractive potential field or to the obstacle for the repulsive one.

Introduction

Path planning is used to find a suitable path between two points (mostly provided by the GPS) while avoiding obstacles in the environment. These obstacles can be dynamical or static. The notion of danger is therefore necessary to avoid a type of obstacle in the most harmonious way. Research on potential field methods has been extensively studied [1, 2, 3, 4, 5]. However, most methods are generally adapted for a static environment or do not take into account the type of obstacle (see e.g. [6, 7]). [8] have improved work on artificial potential fields by taking into account the obstacle dynamics. In this sense, [9] and [10] have interpreted the attractive field as a control loop ensuring stability degree robustness of the trajectory towards mass variations of the ego-vehicle and disturbances by taking into account the position and speed of the target as defined by [8] (see Fig. 1). Also, a novel interpretation of robust control is proposed in [5] for autonomous vehicle. The objective of this article is to present a new potential attractive and repulsive field adapted to a dynamical 3D environment that ensures the robustness of the trajectory. Potential fields are well adapted for drone applications because its holonomic model can be identified by a point mass. The potential field method allows this mass to be taken into account for both attractive and repulsive. The concept of danger will also be taken into account, the obstacles will be considered as known and the method makes it possible to avoid the obstacle with a softer trajectory according to the obstacle type, in other words, its dangerousness (pedestrian, buildings, bicycle, car etc.). In Ge & Cui, no distinction is proposed to differentiate the dangerousness of obstacles (it is safer to go nearer a wall than a human). Therefore, Weyl repulsive potential definition has introduced a fractional degree to distinguish obstacles with their dangerousness. By gaining on differentiating obstacle danger, the dynamical behaviors of obstacle has been lost. Therefore, the paper proposes a new definition of attractive and repulsive field that takes into account both dangerousness and dynamics of the obstacles. Moreover, it is often difficult to scale the attractive and repulsive potential forces. A methodology is proposed to efficiently scale them.
A fractional attractive force is presented in section 2. Section 3 presents a new dynamical fractional repulsive force. To finally conclude in section 4.

Fractional Attractive Force

In [10], the [8] method has been reinterpreted as a control loop, see Figure 1.
This virtual attractive force is defined by:

$$F_{att} = \alpha_p \left(\boldsymbol{p}_{tar} - \boldsymbol{p}_{ego}\right) + \alpha_v \left(\boldsymbol{v}_{tar} - \boldsymbol{v}_{ego}\right) \tag{1}$$

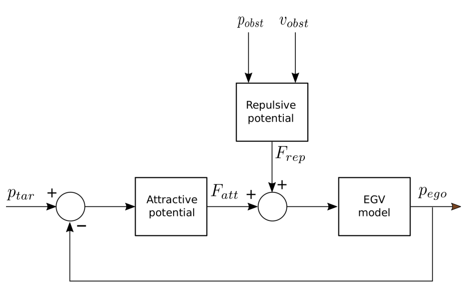

Figure 1: Dynamical interpretation of Ge and Cui attractive and repulsive forces

where $\boldsymbol{p}_{tar}$ and $\boldsymbol{p}_{ego}$ respectively are the real-time positions of the target and the ego-vehicle (EGV). $\boldsymbol{v}_{tar}$ and $\boldsymbol{v}_{ego}$ respectively are the real-time speeds of the target and the ego-vehicle. α_p and α_v are positive constants that define a lead-phase controller.
Introducing the error $e(t) = \boldsymbol{p}_{tar} - \boldsymbol{p}_{ego}$, and considering the fractional derivating of the velocity, it then comes:

$$F_{att} = \alpha_p e(t) + \alpha_v \frac{d^n e(t)}{dt^n}, \tag{2}$$

where $\boldsymbol{a}_{tar}$ and $\boldsymbol{a}_{ego}$ respectively are the real-time acceleration of the target and the ego-vehicle and m_{ego} is the mass of the ego-vehicle.
Under zero initial conditions, the Laplace transform of relation (2) gives:

$$F_{att}(s) = (\alpha_p + \alpha_v s^n)\, E(s), \tag{3}$$

where $E(s)$ is the transform Laplace of $e(t)$.

Fractional Repulsive Force

Ge & Cui potential field definition depends both on the distance ρ between the EGV and the obstacle, and their relative velocities v_{RO}. Weyl potential field solely depends on the distance while distinguishing obstacle dangerousness with order n. Therefore, it is proposed to differentiate the obstacle dangerousness by keeping the order n in the Weyl repulsive field definition, and by adding distance and relative speed to add reactivity to the obstacle. The new fractional repulsive potential becomes:

$$U_{rep}(\boldsymbol{p}, \boldsymbol{v}) = \frac{\left(\rho_s(\boldsymbol{p}, \boldsymbol{p}_{obs}) - \rho_m(\boldsymbol{v}_{RO})\right)^{n-2} - \rho_{max}^{n-2}}{\rho_{min}^{n-2} - \rho_{max}^{n-2}}, \tag{4}$$

from where one draws the following repulsive forces:

$$F_{repv} = \eta \frac{(n-2)\left(\rho_s(\boldsymbol{p}, \boldsymbol{p}_{obs}) - \rho_m(\boldsymbol{v}_{RO})\right)^{n-3} \boldsymbol{v}_{RO}}{\rho_s(\boldsymbol{p}, \boldsymbol{p}_{obs})\, a_{max} \left(\rho_{min}^{n-2} - \rho_{max}^{n-2}\right)} \boldsymbol{v}_{RO\perp} \boldsymbol{n}_{RO\perp} \tag{5}$$

and

$$F_{repp} = \eta \frac{(n-2)\left(\rho_s(\boldsymbol{p}, \boldsymbol{p}_{obs}) - \rho_m(\boldsymbol{v}_{RO})\right)^{n-3} \left(1 + \frac{\boldsymbol{v}_{RO}}{a_{max}}\right)}{\left(\rho_{min}^{n-2} - \rho_{max}^{n-2}\right)} \boldsymbol{n}_{RO}. \tag{6}$$

Now, the repulsive potential field function takes into account an order n to manage obstacle avoidance according to its dangerousness and the obstacle speed to operate in a dynamical environment.

Conclusion

In trajectory planning, artificial potential fields provide good results for trajectory planning in dynamical environments. It remains essential for real-time application and allows a good reactivity of the EGV. The Ge & Cui force allows taking into account the velocity of obstacles but it is not robust to a change in mass. The Weyl potential force associates a degree of danger with an obstacle. A new dynamical fractional attractive and repulsive field is presented allying both advantages and guarantees robustness due to mass variations. This method takes into account the obstacle dynamical aspects such as positions and speeds, and associates dangerousness to a fractional order. The fractional regulator in an attractive form, which allows robustness in terms of EGV mass variations.

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