Dipole Flow Field for Dependable Path Planning of Multiple Agents

Lan Anh Trinh, Mikael Ekström, and Baran Cürüklü

Abstract— **This paper presents a novel approach of path planning for a group of mobile robotic agents working together in a dynamic environment. To do so, the movements of agents are navigated by a vector field of a static flow field and a dynamic dipolar field. The static flow field is formulated based on the any-angle path planning algorithm Theta* with an aim to attract agents to their goals and to avoid obstacles in the map. Meanwhile, the dynamic dipole field pushes agents far away based on their respective moving directions when they tend to collide with other moving agents. The combination of the two fields results in a safe path planning algorithm as well as the deterministic convergence of this algorithm to navigate agents to desired goals. The effectiveness of the proposed approach has been evaluated with simulations.**

I. Introduction

Recently developments in autonomous robots open new challenges in research areas of robotics, especially, in motion planning and control. In particular, the control system should be able to provide robotic agents a reliable control when they are working in a group or in collaboration with one or several humans in complex and dynamic environments. In such scenarios, the agents are not only moving to reach their goals, i.e. certain locations, but are also aware of the others' movements to find a collision-free path for moving. Thus, this paper aims at providing a dependable, i.e. safe, reliable and effective, path planning for a group of moving robotic agents.

Path planning, motion planning or navigation in robotics have been investigated intensely and for a very long time. One of the most conventional yet effective approaches for the navigation of an agent in a large map is related to a family of A* searching algorithms, which aims at searching for the shortest paths [1]. Among this family of algorithms, the A* variant of any-angle path planning algorithms like Theta* [1] deals with a more smooth path with few turns for a robotic agent. Although A*-based algorithms are effective for complicated maps, their computations are rapidly increasing that is proportional to the size of the map, in addition, their formulation for dynamic environment with multiple moving agents has not been well investigated.

To address the interactions of agents and obstacle avoidance in path planning, potential field and its variants [2, 3] have been proposed. The potential field is calculated at every location of the map to determine the direction of the movement of an agent to reach the destination. Usually, the field consists of the repulsive field to push the agent away from the obstacles, and an attractive field to pull the agent to the goal. Nevertheless, due to the lack of global information of a feasible path to the destination, the repulsive field may repulse the agent to reach other obstacles, and somehow the agent may be trapped into a local optimum and loose its way to converge to the goal. Similarly, several works of vector fields to take into account the interactions of different types of agents, and more comprehensive vector field to avoid local optimization are introduced in [4]. However, it is assumed that the moving velocities of agents are also important factors, which can affect the path planning of the whole system. To the best of our knowledge, most of conventional approaches attempt to generate the pushing forces based only on the location of the agents while, in this work it is assumed that, those should be better aligned with the moving direction as well as the velocity magnitude of different agents.

In this paper, a novel method for path planning of mobile agents in a dynamic environment has been proposed to address the aforementioned issues. Firstly, the method employs Theta* algorithm to initialize the paths from a starting point to a goal for a set of agents. As the computations of Theta* algorithm is costly, the algorithm is only performed when there is a significant change on the static map of environment. To deal with dynamic movements of agents, a flow field along the configured path is defined to navigate the agent to reach the goal even the planned trajectories of the agent are changed. In addition, a dipole field is calculated to avoid the collision of agents with respect to their moving directions. The theory of dipole field is borrowed from physics to determine the interaction of multiple magnets in magnetic field. In this work, each agent is assumed to be a source of magnetic dipole field in which the magnetic moment is aligned to the moving direction of the agent and the magnitude of the magnetic moment is proportional to the velocity of the agent. The magnetic dipole-dipole interaction generates repulsive forces to help the agents to avoid collision. Due to the magnetic forces, the agent may be deviated from the planned path, the static flow field is activated to attract the agent back to continue reaching the goal. Both flow field and dipole field are combined to assure a safe and robust, i.e. dependable, path of each agent from the starting point to the goal.

The remains of the paper describes the methodology and the simulation of the proposed approach.

II. Dipole Flow Field for Path Planning

A. Static Flow Field

To configure the shortest paths from the starting to the ending points of each agent in a map, the Theta* algorithm is applied. The Theta* algorithm is chosen because it is able to generate a

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Lan Anh Trinh is PhD student at School of Innovation, Design and Technology, Malardalen University 721 23 Västerås, Sweden (corresponding author to provide e-mail: anh.lan@mdh.se).

Mikael Ekström, and Baran Cürüklü are now with the School of Innovation, Design and Technology, Malardalen University 721 23 Västerås, Sweden (e-mail: mikael.ekstrom@.mdh.se, and baran.curuklu@mdh.se).

less zigzaggy path than those generated by the A* algorithm and its variants. It is noted that the shortest path found by Theta* is the connection of several line segments. The static flow field is created within the neighbor of the line segments. For each path, it is assumed that there are n line segments from the start to the end points. Each line segment i is presented in a vector form of $\boldsymbol{x}(t) = \boldsymbol{a_i} + t\boldsymbol{n_i}$ where $\boldsymbol{a_i}$ is the starting of the line segment and $\boldsymbol{n_i}$ is the unit vector of the line. The flow field force at the point $\boldsymbol{p}$ close to the provided path found by Theta* is calculated by $\boldsymbol{F}_{flow}(\boldsymbol{p}) = F_a(\boldsymbol{p}) + \boldsymbol{F}_r(\boldsymbol{p})$ where $F_a(\boldsymbol{p})$ is the attractive force to draw agent back to the configured path and $\boldsymbol{F}_r(\boldsymbol{p})$ is the repulsive force from nearby static obstacles. The formulation of the flow force is described in Fig. 1.

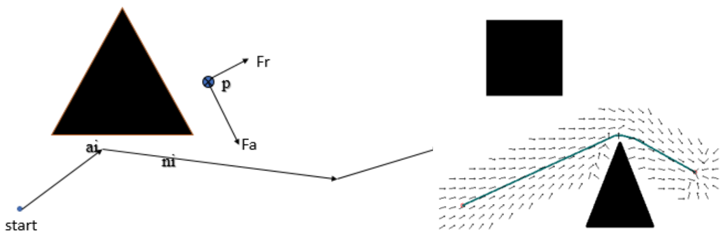

Figure 1. The formulation of flow field.

The attractive force is computed by $F_a(\boldsymbol{p}) = \min(F_{a_i}(\boldsymbol{p}))$ where the $F_{a_i}(\boldsymbol{p})$ is the attractive force of a point to each line segment and is expressed by,

$$F_{a_i}(\boldsymbol{p}) = (1 - e^{-k_1 d(p,ni)})\big((\boldsymbol{a_i} - \boldsymbol{p}) - ((\boldsymbol{a_i} - \boldsymbol{p}).\boldsymbol{n_i})\boldsymbol{n_i}\big) + k_2 e^{-k_1 d(p,ni)}\, \boldsymbol{n_i} \quad (1)$$

where $d(\boldsymbol{p}, \boldsymbol{n_i})$ is the distance from the point $\boldsymbol{p}$ to the line segment *i-th*, k_1, k_2 are constants. The repulsive force $\boldsymbol{F}_r(\boldsymbol{p})$ is formulated in a similar way to conventional approaches [2].

B. Dynamic Dipole Field

To cope with the problem of collision avoidance, the dipole field is generated. Each agent can be seen as a source of a magnetic dipole field in which the magnetic moment is proportional to the moving vector of the agent. In consequence, the magnetic field $\boldsymbol{M}_R$ of the magnetic dipole is expressed by $\boldsymbol{M}_R(\boldsymbol{m}, \boldsymbol{d}) = \rho\big(3(\boldsymbol{m}.\hat{\boldsymbol{d}})\hat{\boldsymbol{d}} - \boldsymbol{m}\big)$ where $\boldsymbol{m}$ is dipole moment vector, $\boldsymbol{d}$ is the distance vector, $\hat{\boldsymbol{d}} = \boldsymbol{d}/d$ is the unit vector with $d = \|\boldsymbol{d}\|$, and ρ is a constant. Correspondingly, the repulsive force of an agent j on an agent k can be formulated by,

$$\boldsymbol{F}_{dipole}(\boldsymbol{m}_j, \boldsymbol{m}_k, \boldsymbol{d}) = \frac{3\rho}{d^5}\left[(\boldsymbol{m}_j.\boldsymbol{d})\boldsymbol{m}_k + (\boldsymbol{m}_k.\boldsymbol{d})\boldsymbol{m}_j + (\boldsymbol{m}_j.\boldsymbol{m}_k)\boldsymbol{d} - \frac{5(\boldsymbol{m}_j.\boldsymbol{d})(\boldsymbol{m}_k.\boldsymbol{d})}{d^2}\boldsymbol{d}\right] \quad (2)$$

where $\boldsymbol{m}_j, \boldsymbol{m}_k$ are the dipole moment of the agents and $\boldsymbol{d}$ is distance vector between the agents. The magnetic force $\boldsymbol{F}_{dipole}(\boldsymbol{m}_j, \boldsymbol{m}_k, \boldsymbol{d})$ is aligned with the direction of $\boldsymbol{m}_j$ and $\boldsymbol{m}_k$.

C. Dipole Flow Field

The dipole flow field for an agent j is formulated by integration of the static flow field and the dynamic dipole field as

$$F_{dipole\ flow} = \alpha \boldsymbol{F}_{flow}/\|\boldsymbol{F}_{flow}\| + \beta \sum_k \boldsymbol{F}_{dipole}(\boldsymbol{m}_j, \boldsymbol{m}_k, \boldsymbol{d}) \quad (3)$$

and the changes of the agent position is updated by $\propto F_{dipole\ flow}/\|F_{dipole\ flow}\|$, α, β are constants.

III. Simulation Results

The whole algorithm has been evaluated with the synthetic map of the binary image where the white pixels are available areas and black pixels are obstacles. The path planning with dipole flow field for three agents are described in Fig. 2.

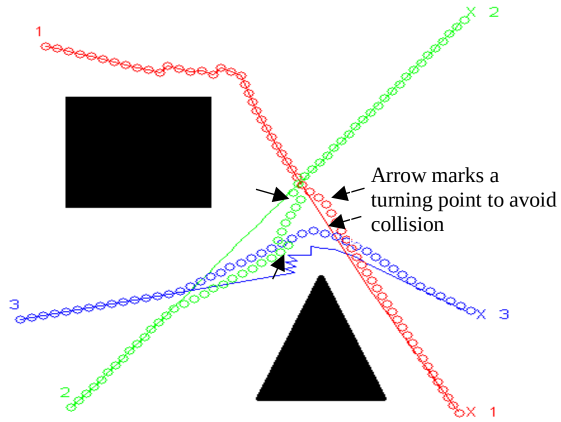

Figure 2. The simulation of dipole flow field for path finding. Agents are represented by red, green, and blue (marked by number 1-3). The ending point of the paths is marked with 'X'. The solid paths are found by only flow field where the agent 2 has collisions with the agent 1 and 3. Meanwhile the paths with circles found by the combination of flow and dipole field has no collision.

IV. Conclusion

This paper has introduced a novel approach of combining flow and dipole fields for path planning in robotics. The simulation results showed that the robotic agents are well routed to the destinations while possible collisions with other agents are taken into account. In future, the work will be extended with different classes of agents [4] and with multiple heuristics of A*[5] to consider more dependability factors and constraints on the path planning problems. The intention is also to validate the algorithm using physical robots and humans in outdoor settings, that resemble the qualities of construction sites.

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