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Promoting collective motion of self-propelled agents by discarding short-range interactions

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HIGHLIGHTS

- We study the collective motion of self-propelled agents with the restricted view.
- The field of view of each agent is an annulus.
- Compared with the circular view, the annular view promotes the collective motion.

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ABSTRACT

We study the collective motion of self-propelled agents with the restricted view. The field of view of each agent is an annulus bounded by the outer radius r and inner radius αr, where α is a tunable parameter. We find that there exists an optimal value of α leading to the highest degree of direction consensus. This phenomenon indicates that there exists superfluous communication in the collective motion of self-propelled agents and short-range interactions hinder the direction consensus of the system. The value of optimal α decreases as the absolute velocity increases, while it increases as the outer radius r and the system size increase. For a fixed value of α, direction consensus is enhanced when the absolute velocity is small, the outer radius or the system size is large.

1. Introduction

The collective motion is a ubiquitous phenomenon in nature, examples of which include bird flocks [1–4], fish schools [5], insects swarms [6,7], bacteria colonies [8,9], and active granular media [10]. Much effort has been devoted to modeling the dynamic properties of swarms [11–21]. A particularly simple but rich model was proposed by Vicsek et al. [22]. In the Vicsek model (VM), self-propelled agents move with the same absolute velocity in a square-shaped cell with the periodic boundary conditions. At each time step, every agent updates its direction according to the average direction of the agents' motion in its neighborhood. The neighborhood of an agent *i* is composed by agent *i* itself and those agents who fall in a circle of sensing radius that centered at the current position of *i*. It has been demonstrated that all agents will converge to the same direction on a macroscopic scale when the density of the system is high and the noise is small enough [23].

The VM and its variations have attracted much attention in the past decade. Grégoire and Chaté found that the onset of collective motion in the VM as well as in related models with and without cohesion is always discontinuous [24]. Huepe

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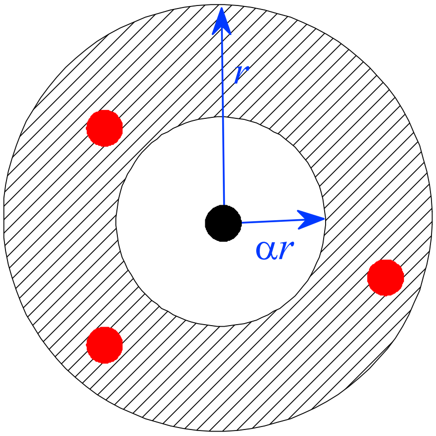

Fig. 1. The sketch map of the annular view. The red (gray) circles which fall in the annular region (the hatched area) are the neighbors of the black circle. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and Aldana studied intermittency and clustering in the VM [25]. Yang et al. considered a power-law distribution of sensing radius which can enhance the convergence efficiency [26]. Li et al. proposed an adaptive velocity model in which each agent not only adjusts its moving direction but also adjusts its speed according to the degree of direction consensus among its local neighbors [27]. Tian et al. discovered that there exists an optimal view angle, leading to the fastest direction consensus [28]. Gao et al. found that the introduction of the weight based on the size of neighborhood [29] and the restriction of the maximal angle change [30] can promote the collective motion of self-propelled agents. Schubring and Ohmann proposed a density-independent modification of the VM in which an agent interacts with neighbors defined by Delaunay triangulation [31]. Peruani and Bär investigated the cluster size distribution of self-propelled agents [32].

In the original VM, the field of vision for every agent is a complete circle with the radius r. In this paper, we propose a restricted view VM, where the view of each agent is an annulus with the inner radius αr and the outer radius r. Here α is a tunable parameter ($0 \le \alpha \le 1$). Interestingly, we find that there exists an optimal value of α, leading to the highest degree of direction consensus.

The paper is organized as follows. In Section 2, we introduce the restricted vision VM. Simulation and discussion are given in Section 3. The paper is concluded in Section 4.

2. The distance-based influence model

We consider N agents moving in the two-dimensional plane without periodic boundary conditions [27,30]. Initially agents are randomly distributed on a region of $L \times L$ rectangle with random directions. Note that this rectangle does not represent the boundary for motion, but only restricts the initial distribution of positions of agents. Each agent has the same absolute velocity v_0. The view of every agent is an annulus with the inner radius αr and the outer radius r, where α is a tunable parameter ($0 \le \alpha \le 1$). At time t, agents i and j are neighbors only if

$$\alpha r < \|\mathbf{x}_i(t) - \mathbf{x}_j(t)\| < r, \tag{1}$$

where $\mathbf{x}_i(t)$ and $\mathbf{x}_j(t)$ denote the position of agent i and agent j at the time t respectively. The sketch map of the annular view of an agent is shown in Fig. 1. The position of a specific agent i is updated according to

$$\mathbf{x}_i(t+1) = \mathbf{x}_i(t) + v_0 \mathrm{e}^{\mathrm{i}\theta_i(t)}. \tag{2}$$

Its direction is updated as

$$\mathrm{e}^{\mathrm{i}\theta_i(t+1)} = \mathrm{e}^{\mathrm{i}\Delta\theta_i(t)} \frac{\sum_{j\in\Gamma_i(t)} \mathrm{e}^{\mathrm{i}\theta_j(t)}}{\left\| \sum_{j\in\Gamma_i(t)} \mathrm{e}^{\mathrm{i}\theta_j(t)} \right\|}, \tag{3}$$

where $\Delta\theta_i$ denotes the white noise (we set $\Delta\theta_i = 0$ in this paper), $\mathrm{e}^{\mathrm{i}\theta(t)}$ is a unit directional vector, and $\Gamma_i(t)$ is the set of neighbors of agent i (including agent i itself).

When $\alpha = 0$, our model is reduced to the original VM, where the view of each agent is a whole circle.