# Flocking Motion, Obstacle Avoidance and Formation Control of Range Limit Perceived Groups Based on Swarm Intelligence Strategy

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Abstract—In nature there are many biological organisms show that the collective behavior in which implicating the potential interior operational principle. Based on the analysis of various biological swarms of dynamic aggregation mechanism, the swarm's flocking motion, obstacle avoidance and formation behaviour control was studied based on intelligent agents that have limited detection range, an isotropic perceived group dynamic model is proposed in this paper. The theoretical analysis confirm that, based on the strategy of combining artificial potential with velocity consensus, under an interplay between linearly bounded attraction and unbounded repulsion force among the individuals in the group, as a result of security safeguard of the safe distance between individuals, the individuals in the group during the course of coordinative motion can realize the local collision-free stabilization of particular predefined a desired symmetric mutual geometrical configuration formation and behaviour. Better self-adaptability of aggregating surrounding environment is embodied out in the proposed model. The results of simulation show that the algorithm is valid.

*Index Terms*—limited-range perceived groups; flocking motion control; obstacle avoidance; formation behaviour control; stabilization; the swarm system

#### I. INTRODUCTION

In the natural world, population appears in patterns of aggregation (flocking/ grouping/ herding - a natural mechanism important for the survival of individuals). Aggregation (or gathering together) is a basic behavior exhibited by many swarms in nature, including simple bacteria colonies, flocks of birds, schools of fish, and herds of mammals. Such behavior of biological swarms is observed to be helpful in meeting various tasks such as avoiding predators, increasing the chance of finding food, etc. This can be explained by the relative appropriateness of an aggregated swarm structure to meet these tasks collaboratively as compared to a non-aggregated setting. Because of the same reason, aggregation is a desired behavior in engineering multi-agent dynamic systems as well. Moreover, many of the collective behaviors being seen in biological swarms and some behaviors to be possibly implemented in engineering multi-agent dynamic systems emerge in aggregated swarms. Therefore, studying the dynamics and properties of swarm aggregations is important in developing efficient cooperative multi-agent dynamic systems. Foraging can be considered as a constrained form of aggregation, where the environment affects the motion or behavior of agents. Hence, for a foraging task, the swarm coordination and control scheme to be developed need to guarantee aggregation in the favorable regions while avoiding unfavorable ones. Aggregation in biological swarms usually occurs during social foraging. Social foraging has many advantages such as increasing probability of success for the individuals. Therefore, social foraging is an important problem since swarm studies in engineering may benefit from similar advantages [1]. Flocking, in general, can be defined as collective motion behavior of a large number of interacting agents with a common group objective [2]. Flocking, also, can be considered as a group of mobile agents is said to asymptotically flock, when all agents attain the same velocity vector, distances between agents are stabilised and no collisions occur between them [3].

Flocking motion can be seen everywhere in nature, e.g., flocking of birds, schooling of fish, and swarming of bees. Understanding the mechanisms and operational principles in them can provide useful ideas for developing distributed cooperative control and coordination of multiple mobile autonomous agents/robots. In recent years, distributed control/coordination of the motion of multiple dynamic agents/robots has emerged as a topic of major interest [4].

In Reference [5], an isotropic perceived group dynamic model in which the detection range is considered as finite is proposed by us. Dynamic change of the environment, local observation and nonlinear characteristics are ubiquitous phenomena in nature, but the study is very difficult and it has profound engineering significance. Thus, the chief research objective of the paper is to apply the swarm dynamic model of range limited-perceive groups to propose reasonable solving scheme based on the analysis of various biological swarm systems on the effect of flocking motion behavior mechanism in an *n*-dimensional Euclidean space. And then to consider the collision-eluding and formation behavior control of such swarm systems.

The article is organized as follows. In section 2 we cite the corresponding *M*-member "individual-based" Lagrangian isotropic continuous time social foraging swarm model in Ref. [5] to utilize it for performing analyses on flocking motion, collision-eluding and formation behavior control of intelligent agents. Finally, concluding remarks are stated in section 3.

# II. THE MAIN RESULTS AND ANALYSIS OF ISOTROPIC FLOCKING SWARM

# A. Problem formulation of Modeling of flocking swarm

Social animals or insects in nature often exhibit a form of emergent collective behavior known as 'flocking'. The flocking model is a bio-inspired computational model for simulating the animation of a flock of entities. It represents group movement as seen in the bird flocks and the fish schools in nature. In this model, each individual makes its movement decisions on its own according to its neighboring members in the flock and the environment it senses. As the swarming behavior is a result of an interplay between a short-ranged repulsion and a longranged attraction between the individuals and interplay with environment in the individual-based (or Lagrangian) frameworks models. So, these simple local rules of each individual generate a complex global behavior of the entire flock.

Based on the inspiration from biology, referring to the known results in literatures [5], we consider a swarm of M individuals (members) in a *n*-dimensional Euclidean space, assume synchronous motion and no time delays, and model the individuals as points and ignore their dimensions. The equation of collective motion of individual *i* is given by as follows

$$\dot{x}^{i} = -\nabla_{x^{i}} \sigma(x^{i}) + \sum_{j=1, j \neq i}^{M} g(x^{i} - x^{j}), i = 1, \cdots, M$$

Where  $x^i \in \mathbb{R}^n$  represents the position of individual  $i = -\nabla_{x^i} \sigma(x^i)$  stands for the collective motion's

*t*; *x*<sup>2</sup> (*x*<sup>2</sup>) stands for the collective motion's direction resting with the different social attractant/repellent potential fields environment profile

around individual i;  $g(\cdot)$  represents the function of attraction and repulsion between the individuals members. The above  $g(\cdot)$  functions are odd (and therefore symmetric with respect to the origin). This is an important feature of the  $g(\cdot)$  functions that leads to aggregation behavior [1].

The attraction/repulsion function that we consider is

$$g(y) = -y \left[ g_a(\|y\|) - g_r(\|y\|) \right] = -y \left[ a - \frac{b(v-r)}{(r-\rho) \|y\|^2} \right]_{.(2)}$$

Where,  $a, b, v, r, \rho$  are arbitrary constants, is normal number,  $v > r > \rho > 0$ , the 2-norm  $||y|| = \sqrt{y^T y}$ . The numerical imitation of  $g(\cdot)$  as Fig. 1 and Fig. 2 shows.



Figure 1. Linear attraction/unbounded repulsion function



Figure 2. Convergent trajectories of linear attraction/unbounded repulsion swarms

In Fig. 2, blue "\*" represent original position, black " • " represent final position, read "." represent convergent trajectories of individuals.

#### B. Numerical simulations of flocking motion

Based on the same simulation method, process and parameters given in reference [6], includes Plan, Quadratic, Gaussian, Multimodal Gaussian attractant/repellent social potential field profiles functions, we performed simulations, numerical imitation results as follows



Figure 3. Plan social potential field



Figure 4. Collective behavior of swarm in plane social potential field of the range limited-perceive swarm model



Figure 5. Quadratic social potential field



Figure 6. Collective behavior of swarm in quadratic social potential field of the range limited-perceive swarm model



Figure 7. Gaussian social potential field



Figure 8. Collective behavior of swarm in Gaussian social potential field of the range limited-perceive swarm model



Figure 9. Multimodal Gaussian social potential field



Figure 10. Collective behavior of swarm in Multimodal Gaussian social potential field of the range limited-perceive swarm model

The theoretical analysis and simulation results in this paper confirm that the convergence properties of the range limited-perceive swarm model are better than the model in reference [6].

#### C. The collision-eluding behavior control

Based on the same simulation method, and process in reference [7], by using the range limited-perceive swarm model, we obtain the following simulation results as shown in Fig. 11 is for 100 individuals (in the original region  $40 \text{ cm}^{\times} 40 \text{ cm}$ ) to traverse through an environment with five obstacles.



Figure 11. The track of the range limited-perceive swarm in multiobstacle environment

Where the red ball's center represent the global object position is at (78 cm, 78 cm) and the simulation region is 80 cm  $\times$  80 cm in the space. The five black balls' center is repectively: (35 cm, 45 cm), (48 cm, 35 cm), (52 cm, 50 cm), (50 cm, 45 cm) and (65 cm, 65 cm). The five black balls represents the obstacles in the environment. Where the blue "\*" represent original position, the yellow "." represent the convergent trajectories of individuals in swarm. The result shown in Fig. 11 reify our theories, in multi-obstacle environment, the individuals in the range limited-perceive swarm during the course of coordinative motion can realizes the collision-eluding obstacles, mutual aggregating behavior and arrive at object position finally.

Numerical simulation experiments show that the range limited-perceive swarm model can guarantee collision avoidance in the swarm in multi-obstacle environment.

#### D. The formation behavior control

The formation concept, first explored in the 1980's to allow multiple geostationary satellites to share a common orbital slot [8], has recently entered the era of application with many successful real missions [9].

Formation control is an important issue in coordinated control for multi-agent systems (such as, a group of unmanned autonomous vehicles (UAV)/robots). In many applications, a group of autonomous vehicles are required to follow a predefined trajectory while maintaining a desired spatial pattern. Moving in formation has many advantages over conventional systems, for example, it can reduce the system cost, increase the robustness and efficiency of the system while providing redundancy, reconfiguration ability and structure flexibility for the system. Formation control has broad applications, for example, security patrols, search and rescue in hazardous environments. Research on formation control also helps people to better understand some biological social behaviors, such as swarm of insects and flocking of birds [10].

Control of systems consisting of multiple vehicles (or agents) with swarm dynamical models are intend to perform a coordinated task is currently an important and challenging field of research. Formation of geometric shapes with autonomous robots is a particular type of the coordination problem of multi-agent systems [11].

In fact, we consider formation control as a special form of swarm aggregation, where the final aggregated form of the swarm is desired to constitute a particular predefined geometrical configuration that is defined by a set of desired inter-agent distance values. This is achieved by defining the potential function to achieve its global minimum at the desired formation. For this case, however, due to the fact that potential functions may have many local minima, the results obtained are usually local. In other words, unless the potential function is defined to have a single (unique) minimum at the desired formation, convergence to that formation is guaranteed only if the agents start from a "sufficiently close" configuration or positions to the desired formation. Some of these works are based on point mass agent dynamics [1].

So, by use of the range limited-perceive swarm dynamical model, based on artificial potential field (APF) function and Newton-Raphson iteration update rule to numerical imitation analyze how a large number of UAV/robots namely Large-scale swarm system can form desired particular predefined an approximation of a simple convex polygon or circle formation in the plane by collective motion, related the range limited-perceive swarm pattern formation behavior results examples as follows



Figure 12. The ideal formation configuration of the line segment for 2 vehicles



Figure 13. Convergent trajectories of the ideal formation configuration of line segment for 2 vehicles in plane



Figure 14. Congregated positions of entire of the ideal formation configuration of the line segment for 2 vehicles in plane







Figure 16. Convergent trajectories of the ideal formation configuration of the line segment for 3 vehicles in plane



Figure 17. The ideal formation configuration of the equilateral triangle for 3 vehicles



Figure 18. Convergent trajectories of the ideal formation configuration of the equilateral triangle for 3 vehicles in plane



Figure 19. Congregated positions of entire of the ideal formation configuration of the equilateral triangle for 3 vehicles in plane



Figure 20. The ideal formation configuration of the diamond for 4 vehicles



Figure 21. Convergent trajectories of the ideal formation configuration of the diamond for 4 vehicles in plane



Figure 22. Congregated positions of entire of the ideal formation configuration of the diamond for 4 vehicles in plane



Figure 23. The ideal formation configuration of the parallelogram for 4 vehicles



Figure 24. Convergent trajectories of the ideal formation configuration of the parallelogram for 4 vehicles in plane



Figure 25. Congregated positions of entire of the ideal formation configuration of the parallelogram for 4 vehicles in plane



Figure 26. The ideal formation configuration of the equilateral triangle for 6 vehicles



Figure 27. Convergent trajectories of the ideal formation configuration of the equilateral triangle for 6 vehicles in plane



Figure 28. Congregated positions of entire of the ideal formation configuration of the equilateral triangle for 6 vehicles in plane

In above graphs, black "\*" represent original position, read "。" represent final position, blue "." represent convergent trajectories of individuals, the polygonal vertex shows the final numerical imitation configuration position of UAV/robots. Considering the convenience of

simulation, let  $\nabla_y \sigma(y) = 0$ . In the figures of the relations between sides and angles of the desired formation configuration, black spheres represent final configuration position,  $V_i, i = 1, \dots, M$ . represent different vehicles in the swarm systems.

As mentioned above, the particular predefined convex polygon geometrical configuration formations were discussed.

Following, we will analyze and discuss the circle formation behavior control problem.

The circle formation is a good starting point for many symmetric formations. Move in circle behavior needs the

calculation of the circle radius. While  $M \rightarrow \infty$ , we utilize arc length equivalency replacement of the desired distances between the individuals in the swarm. The arc radius is calculated by knowing the number of UAV/robots and the desired distance between them [12]. Fig. 29 is an illustrative example for four UAV/robots. The same idea can be used for N UAV/robots. As shown, the radius of the circle can be computed as follows form:

$$\theta = 2\pi / N. \quad (3)$$

$$r = \frac{D_d}{2 * \sin(\theta / 2)} \quad (4)$$

$$D_d \approx l = \frac{\sigma m}{180} \tag{5}$$

Where  $D_d = d_{ij}$  is the desired distance between UAV/robots i and j. While, arc length  $l = S_{ij} \approx \left\| V_{ij} \right\|_{.}$  as Fig. 30 shows.



Figure 29. Computing the radius four-robots/vehicles circle



Figure 30. Computing the arc radius of the robots/vehicles path

In this study, the robots/UAV uses a local planning strategy instead of a global strategy. Since the method is iterative, the robot updated its own motion plan at each step utilizing the new position information of other robots forming circle formation. Our objective is to force the robots to form a geometric shape using the above method. Given any initial positions and any desired geometrical formation the robots should locate themselves to the desired inter-robot distances so as to form the desired geometrical shape. With this objective in mind we define the target set for each robot as the set of points that consists of the points defined at the desired distances from the other robots. For instance assume that there are eight robots which are required to form a circle with edge lengths  $D_d = d_{ij}$  as shown in Fig. 31. In this case, note that at each step -after the motion of robots- the positions of these points change and therefore, the target sets will be time-varying and need to be updated. These targets are defined by the robot's desired distance to the other robots in the desired formation.



Figure 31. The desired formation configuration for simulation of the circle for 8 robots/vehicles

Each robot determines its step size according to the relative difference. In some situations robot's step size can be large due to the large relative difference between the agents and this may lead to convergence problems. Therefore, to reach the target or to achieve the desired formation some limitations should be applied on the relative difference obtained as the output of the Newton iteration. For this purpose, let us define the next position of the robot as

$$X_i(k+1) = X_i(k) + \lambda \Delta X_i(k) .$$
 (6)

Where  $\lambda \succ 0$  the step size to be determined by the designer and  $riangle X_i(k)$  is the unit step vector

determining the direction of motion.

Where 
$$\delta_{ij}(k) = \|X_i(k) - X_j(k)\|$$
 is the present

distance between robots/UAV i and J [10].



Figure 32. Convergent trajectories of the desired formation configuration of the circle for 8 robots/vehicles in plane



Figure 33. Congregated positions of entire of the desired formation configuration of the circle for 8 robots/vehicles in plane



Figure 34. Circular formation motion final position of eight UAV/robots: simulation results

Where Fig. 31 shows that the relation between sides and angles of the desired circle formation, black spheres represent final configuration position,  $V_i$ ,  $i = 1, \dots, 8$ .

represent different vehicles in the swarm systems. In Fig. 32, black "\*" represent original position, read "。" represent final position, blue "." represent convergent trajectories of individuals. In Fig. 33, the polygonal vertex shows the final numerical imitation configuration position of UAV/robots. In Fig. 34, black spheres represent final circular configuration position of eight UAV/robots in the plane.

The simulation results in this section reify our theories of formation stabilization for multi-agent systems.

#### **III.** CONCLUSIONS

This paper studied the flocking motion, obstacle avoidance and formation behaviour control problem of a group of isotropic range limited-perceive agents with interaction force between individuals moving in an ndimensional Euclidean space. To solve the problem, based on the inspiration from biology, we proposed an isotropic range limited-perceive swarm model of swarm aggregating behavior for multi-agent system. Meanwhile, the model is a kinematic model. It is fit for individuals in which move basing on the Newton's law in an environment can capture the basic convergence properties of biological populations in nature. Therefore, the final behavior of the swarms described by the model may be in harmony with real biological swarms well. Numerical simulation agrees very well with the theoretical analysis of flocking motion and obstacle-eluding aggregating stability of the swarm systems, the circle formation behavior control and obstacle-eluding aggregating behavior for multi-agent system is analyzed and discussed at last. For further work, the experiments will be conducted in the presence of dynamic obstacles ... etc. Therefore, it is obviously the swarm aggregating results obtained from the isotropic range limited-perceive swarm model which has a definite reference value in the multiagent coordination and control literature.

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