Study on Birds Flocking Formations

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Abstract— **Birds, like many other social animals, demonstrate very structured and complex patterns in their flights collectively without any central coordinating body in a self-organizing way. The theory of swarm intelligence has extended this robust biological insight into artificial systems. Natural Birds flock together broadly in two basic formations- clustering and 'V' pattern. Craig Raynolds's simulation of the artificial birds in 1987 has explained how simple-rule based interactions among individual boids generate complex flocking pattern. Birds flocking is based on two primary factors: the underlying physics of birds' physical properties and the perception mechanism. This study is focused on understanding how the perception mechanism of an individual bird, represented by the input from its visual parameters such as vision angle, vision range, visual obstruction, and the number of birds flocking impact the flocking pattern emergence. This study sweeps the perception parameters to enable each boid to define continuously its flockmates and nearest neighbor, and follow the steering drive. It runs computer simulation on an agent-based modeling software and presents the artificial birds with quantitively different visual perception parameters. The study finds that clustering formation is generally the result of a wide field of vision of each artificial bird, and a drive to seek an unobstructed view is critical for forming 'V' formation.**

***Keywords*— Swarm intelligence, boids, field of vision, clustering formation, 'V' formation, agent-based modelling**

I. Introduction

Social animals like birds or fishes exhibit magnificent and organized movement patterns collectively as if they are moving with a collective goal led by a centralized control system[1]. However, researches on their movement pattern expose that the organized and structured patterns are not an outcome of any centralized control; interaction of individual birds with limited perception and capabilities in a self-organizing way produces the emergence of distinct formations, which are essentially critical for their survival[2][3]. Like many other animals, the evolutionary perspectives and biological insights of birds' life have motivated scientists to investigate how birds move in a group with distinct patterns without collision, explore for food, and avoid predators. The insights of birds flocking, like other swarms, can be extended for the study of artificial life and robotics.

Birds have very dynamic social interaction skills that allow them to fly (specifically move in a space where the complete stationary position attainment is impossible) without collision, group and disperse in the face of an external threat, explore for food and avoid predators[1]. Flocking in a group provides some significant advantages to the birds in the nature such as protection from the predators, increasing the chance of survival statistically in case of any unwanted accident or external threat, benefiting from the result of collective search for food, navigation, and social and mating activities[4][2][5]. For the larger birds, forming some specific structures like 'V'-like formation or compound 'V' formation while flocking provides significant advantages in terms of energy consumption and conservation. The two overwhelming and logical reasons for forming a 'V' pattern during long flights of migratory birds are aerodynamic benefits and vision benefit. Forming a 'V' pattern enables the follower (succeeding) bird to take advantage of the upwash from the wings movement of the preceding bird. This significantly reduces the energy consumption of the follower birds mass. As for the visionary advantages, the birds have an unobstructed view ahead that helps to navigate and avoid obstacles[4][2][1].

Inspired by the wonderful flocking motions of birds, one of the earliest works on simulating birds flocking in the artificial system is carried out by Craig Reynold in his phenomenal work in [4]. He proposed three simple rules for his simulated birds, what he called boid, to imitate the emergence of natural birds flocking. The simplicity of the rules and emergent of complex patterns by the interaction of boids have drawn a lot of interest among scientists in extending the birds flocking simulation into designing more diverse and efficient algorithms and computation models [6] [7][8] for designing robot path control mechanism [9], computer animation and aerial robot or drone design [10] . Further studies on birds' flocking formations were carried out by Nathan et al [2], Seiler et al [11], Lebar Bajec et al [12], Aaron et al [5] and others. An interesting analogy of the birds flocking according to the Social Cognitive Theory can be that the birds adjust their positions in a 3D space avoiding a collision, and humans psychologically adjust their ideas in n-dimensional abstract space without conflicting among them[1]. This analogy was further extended to solve problems by projecting the data into n-dimensional space. Kennedy and Eberhart, inspired by the Birds' diverse and successful flocking techniques, introduced Particle swarm optimization (PSO) as an optimization problem solution in 1995 that continues to be explored by many researchers [13][1][14]. PSO has been successfully implemented in many diverse works such as image analysis applications, video analysis applications, classification problems, and many other applications[1][15].

Motivated by the interesting implications and the scope of work on birds flocking, this study attempts to investigate two flocking behaviors of birds, namely clustering and 'V' formation, under different perception abilities and local rules. The observation of emergent complex patterns by varying perception parameters such as field of vision and limiting the nearest neighborhood is central to this study. In the subsequent sections, literature review and background on the birds flocking are discussed along with the description of methodology and experimental setup including computer-based simulation tests. Finally, the findings and results are discussed.

II. Background and Previous Works

Swarm intelligence was first introduced as an algorithmic framework for controlling swarm robots by G. Beni and J. Wang in 1989 [1]. A swarm is a large group of small animals, homogenous in nature, that interact individually with one another and the environment in the absence of a centralized control system[1]. Their interactions, apparently very local in nature, result in the emergence of interesting collective accomplishment. While the individual member of the groups has very limited capability and performs a very simple task based on simple rules, collectively they carry out distributed problem-solving at the global level [16]. The motivation for swarm intelligence in the artificial system is drawn from the evidence of the emergence of self-organizing properties in small animals and social insects. In swarm intelligence, the agents are homogeneous in nature, act asynchronously at the individual level without any central control system, equipped with very limited communication capability - mostly through modification of the environment, and are conscious of a small neighborhood [14]. Multiple interactions at the individual level by these agents result in the emergence of complex self-organizing phenomena that can be extended to solve complex problems in artificial systems. Swarm intelligence is now increasingly used to solve a variety of problems in artificial systems.

A large number of birds flying in the sky are also studied as a swarm, and their routine activities illustrate the significance of swarm intelligence. The manifestation of emergent patterns in a self-organizing way in birds flocking is linked to the powerful concept of ‘umwelt’. This concept, first introduced by Von Uexkull in 1934, refers to the “subjective world” or “the self-world” that an organism perceives and experiences[17][18]. The concept goes beyond the sensory organization and perception by embracing the way an animal responds and modifies its environment[18]. The way a bird perceives its world and modifies its environment – other birds and the surrounding world- is an important constituent that contributes to crafting of the local rules for an individual bird[4]. For example, the head and the eye arrangement of a bird provides it a wide field of vision (for Pigeon about 300 degrees), but a small forward-oriented cone due to a small overlap of eyes (refer to Figure y1)[4][1]. This essentially dictates its world and as such its behavior. Therefore, the structural movement formation of the real birds is the outcome of the individual bird’s action based on its perception of its surroundings[4].

Craig Raynolds’s phenomenal work of simulating artificial birds was a significant inspiration towards studying the flocking patterns of birds in computer systems[4]. Raynolds considered flocking as an example of emergence: “where complex global behavior can arise from the interaction of simple local rules”[4]. He assumed the flocking as an aggregated result of interaction between the behaviors of individual birds. Implementing a flock simulation is generally based on the distributed behavioral model that Raynolds called a model of “robust self-organizing distributed system” [4]. To flock, each boid should be able to adjust its behavior with the coordinates of the movement of its flockmates. Essentially, two opposing forces work on each boid in balance, to remain close to flockmates and to avoid collisions while settling in the flock. The basic difference of artificial birds' flocking with traditionally particle systems, as considered in Particle Swarm Intelligence, is that particles do not have any orientation on its vital geometric states, while in Raynolds boids were designed to be concerned with the orientation[4].

Raynolds' proposed rules for each boid work in a self-organizing way and generate flocking formation, usually a cluster of flying birds, as an emergent property. The first rule is ‘Collision Avoidance’ (also mentioned as ‘Separation’ rule) which is to avoid collision with nearby flockmates or obstacles even when changing the direction of flights. The second rule, ‘Velocity Matching’ (‘Alignment’ rule), is about attempting to be in the same velocity with its nearby boids. The third rule states the ‘Cohesion’ of the flockmates where an individual boid tries to stay close to nearby boids[4][15]. These three simple rules are followed by each boid individually, without having complete global knowledge about the flocks.

Another important study on the formation of a V-like pattern in migratory birds flight was examined for computer simulation by Nathan et al[2]. They also proposed three rules that were based on leveraging the core benefits of forming ‘V’ pattern flocking as discussed by various studies. The rules are intended to drive the artificial birds to seek for an unobstructed view ahead, and take the aerodynamic advantage from the upwash produced by the wing movement of the preceding bird[2]. However, their rules are not a contradiction to what Raynolds proposed, rather both sets of the rules are very much comparable. Table 1 shows both sets of the rules to present the congruence between them:

TABLE I
LOCAL RULES FOR FORMING CLUSTERING AND ‘V’ PATTERN

Flocking Rules by Raynolds	V-like formation rules by Nathan et al
Collision Avoidance: Separation	Rule 2: Gap Seeking
Alignment: Velocity Matching	Rule 3: Stationing Rule
Cohesion- staying close: Flock Centering	Rule 1: Coalescing Rule

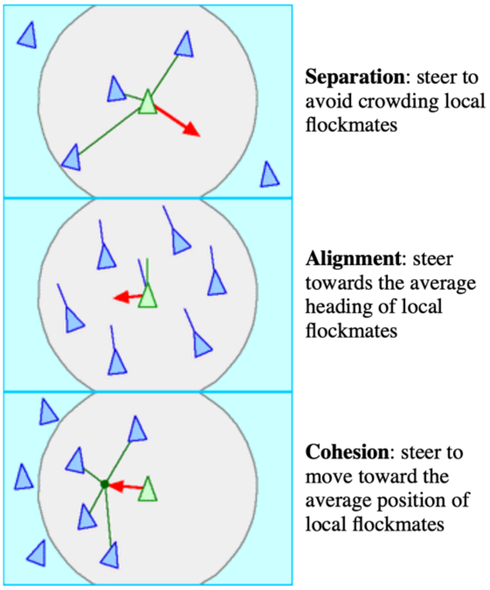

Figure 1: Three rules for boids within the visual range of an individual boid. Taken from [19].

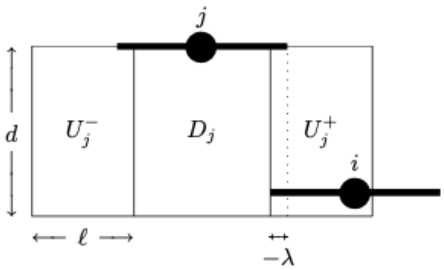

Figure 2: Two birds i and j. Birds i's moves to any sideway to have unobstructed view and its wingspan only overlaps a little or none for taking the advantages of upwash from the bird j. Taken from [2].

In Raynolds's design, each boid has a localized perception about the location of its close neighbors and the nearest neighbor, defined by a radius of influence beyond which it has no idea about the details of the entire flocks (refer to Figure 1). The neighborhood is defined by two parameters, denoted by a vector: one is the distance and the other is the angle from the boid's flight direction. Two complementary rules, collision avoidance and velocity matching, are considered as the critical factors for flocking. While the static nature of the collision avoidance rule is based on the relative position of the boid ignoring its velocity, the dynamic velocity matching rule overlooks the position and focuses on velocity[4][19]. Besides, long-range vision is central for flocking as without it boid would ignore the other boids in a short distance, and they all will fly at their own. Contrarily, once inside the flock, long-range vision can deflect individual boid from the flock if it is not controlled by the cohesion rule. In the case of Nathan et al proposed rules, in addition to achieving a perception about the nearest neighbor, the stationing rule drives the birds to seek a position in any of the sides, oblique to the preceding bird, to get an unobstructed view ahead (refer to Figure 2). While the unobstructed view is achieved, the bird places itself in a position to maximize the aerodynamic benefits of the upwash[2].

However, the arbitration of the local rules is critical for generating desired flocking behavior for both the cases. In Raynolds's boid, each boid generates three different steering behaviors from its perception of the flockmates (close neighbor) and the nearest neighbor. Generally, these steering behaviors are likely to complement each other. But, they might cancel each other if not arbitrated correctly. Averaging the steering requests can cancel each other and result in unpredictable behavior[4]. Therefore, Raynolds's prioritization of the rules (1) collision Avoidance, (2) Velocity Matching, and (3) Flock Centering are applied on prioritized acceleration allocation where each acceleration request is added in an accumulator and compared with individual maximum acceleration urge. A controller produces a whole value which then allocates a percentage/portion of control value to a steering request as per priority. In the case when the control value runs out, then less prioritized request receive less weight and thus has less acceleration effect on the accumulated acceleration result. On the other hand, if no acceleration request is received from any or two other steering behaviors, the control value is normalized and sent to the accumulator. A weighted average is then calculated for the final resultant acceleration value[20][4].

Arbitration of the local rules for Nathan et al is based on prioritization. All boids individually pursue Rule 1(collision avoidance). The other rules are applicable only after the achievement of Rule 1. Then, Rule 2 (gap seeking rule) is applied where each boid seeks the closest position at the rear of the preceding bird by adjusting its position to achieve an unobstructed view. This rule places the boid on one of the sides oblique to its preceding boid. Rule 3 (stationing rule) is more of maintaining Rule 1 and Rule 2 that drives adjustment of the position when needed[2].

Based on the above discussions, it is clear that for artificial birds flocking simulation two aspects are critical; one is the physics of gravity, motions, aerodynamic and mass of the boid, and the other is the perception mechanism[4]. While the first part is related to steering actions, the second part is about creating the drive or stimuli for choosing the steering actions. Perception mechanism typically works when each boid has a perception about three things: of its own, of its neighboring boids and of the rest of the world. Modeling of artificial birds or boids is essentially related to self-orientation and defining response to others (including environment) behaviors[4]. Self-orientation in a boid can be achieved and interpreted by many factors such as in the form of depth of vision and auditory range. Changing the vision capability or changing the definition of near-by flockmates or changing the velocity gain dynamically can produce interesting outcomes, resembling the patterns formed in real birds. Therefore, the investigation on the value of perception parameters and local rules are of interest to many researchers.

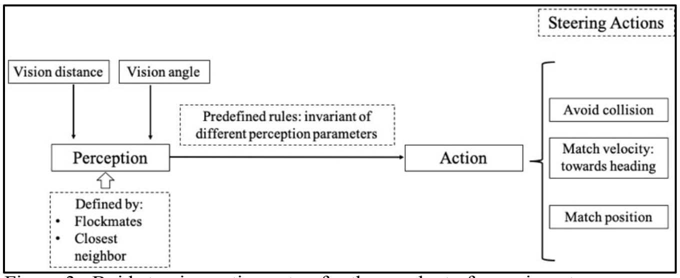

Figure 3: Boid steering action setup for the conduct of experiment.

To study this interesting flocking behavior in birds, modeling biological birds in computer-simulated programs has greater benefits, as constraints are only limited by technology and researchers' inspiration[1]. Essentially, there exist some basic differences between biological birds and artificial birds. In biological birds, individual updates its actions asynchronously, but in most of the simulated programs, artificial birds update their local conditions synchronously [14]. In computer modeling, it is possible to provide resultant input to birds without making them to sense, weigh and calculate the required input for steering actions, making it less complicated[4]. One the other hand, the real bird's perception is contingent on the individual sensory organs and biological functioning, which is very complex to model. However, these differences in many cases are dependent on the research objectives. Given the technological flexibility in modeling artificial birds in computer-simulated programs, this study attempted to observe the emerging property of birds flocking that results from changing different perception parameters in the form of vision distance, vision angle, defining the flockmates and nearest neighbor (refer to Figure 4).

III. EXPERIMENT SETUP AND METHOD

One of the unavoidable limitations in studying the birds flocking patterns is the inadequacy of any objective criteria or numerical indicators to evaluate perfect flocking. The definition of ideal flocking is generally a subjective assessment. Properties such as flying in a group in the same direction with the same speed, navigating obstacles in a collective move, not losing any flockmates during flights are subjective assessments that are hard to quantify. Therefore, the study is designed for observing the stability of two particular flocking patterns: 'V' formation and clustering, and record and evaluate the result subjectively.

Boids flocking together is a function of their perception of neighbors in terms of individual boid's vision angle and vision distance, i.e. how far it can see to consider its flockmate and nearest neighbor. The flocking patterns also depend on the number of boids and the urge to avoid obstruction angle. The experiment was set up to study how the flocking patterns, 'V' formation or clustering, emerge with the change of individual boid's vision parameters with an increasing number of boids. Randomness in the flocking formation with different paraments is stochastic in nature. Therefore, experiments were designed to sweep parameters and averaging the observations to get the data.

The experiments were carried out with Netlogo 6.10.0 [21][22], which is an agent-based modeling software. For this study, 'Flocking'[23] and 'Flocking 'V' Formation'[24] models in the Netlogo software were consulted and required codes were written to simulate experimental settings. Birds in the model are represented by the 'turtles' agents of the software, and flying space is represented by the 'patches' agent. In addition to in-built primitives for both 'turtles' and 'patches', the software allows users to define variables and add procedures according to study requirements. The virtual world in which 'turtles' and 'patches' interact is a two-dimensional grid that can be extended or reduced to meet the experimental requirements[21]. Birds in the model were designed to move (fly) over the space, be conscious of a range of distances from its position to recognize its flockmates and the nearest neighbor, change its speed and direction towards the flockmates, fly in the direction of the entire flock. No particular goal for moving direction was introduced, so the flocks move towards a direction that is produced by the random initial moving directions. The experimental settings for the study was as below:

Environment (Space):	71 X 71, Non-toroidal
Base velocity:	.2 patches/ tick
Velocity adjustment factor for acceleration:	.2
Minimum separation from another boid	1
Maximum turn for separation	5 degrees
Maximum turn for coherence	2 degrees
Maximum turn for alignment	4 degrees

Simulations were carried out by sweeping four parameters: the number of boids, vision distance, vision angle, and obstruction angle. Since the perfect flocking pattern is difficult to measure, the simulation runs were evaluated for stability and formation of basic patterns. All the parameters were varied for each setup, and 5 data readings were recorded and observed to subjectively evaluated to report a pattern and stability.

Number of birds:	{10, 20, 30, 100, 200}
Vision distance:	{5, 10}
Vision angle:	{180, 270, 300, 360}
Obstruction angle:	{0, 60, 90}
Total simulation run:	480 times

IV. RESULTS

Results of simulation run of the experiments are given in subsequent paragraphs.

A. Number of Boids

During simulations run with a population size of 10, 20, 30 with obstruction angle 60 and 90 degrees, stable 'V' formations were formed. Figure 4 shows the stable 'V' formation with the vision of 180 degrees with obstruction angles (results for 10 and 30 number of boids are given at appendix). It was possible to get a 'V' formation for a large number of boids, but not as a compact flock, rather as waves of small clustered ‘V’ formations (refer to Figures 5a and 5b). In the absence of an obstruction angle, boids flock together as a cluster (refer to Figure 6).

B. Vision Distance

Changing of distance resulted in laterally dispersed flocking formation. Figure 7 shows the dispersion caused by doubling vision distance. Results for permutations of numbers of boids with varied vision distances are given in the appendix.

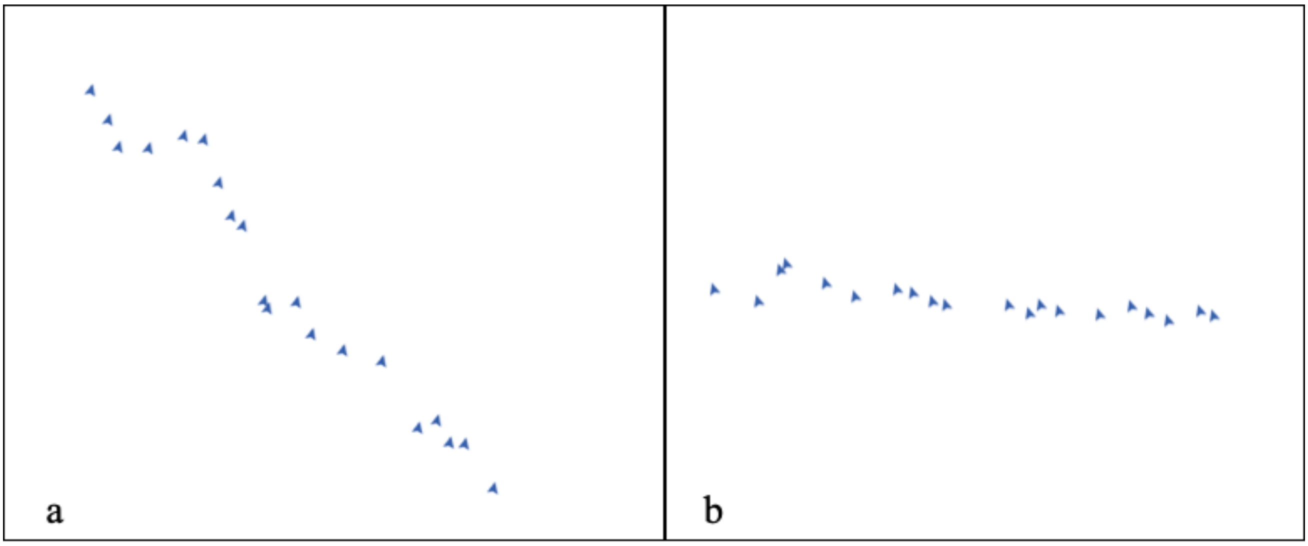

Figure 4 : Snapshot of simulation. 20 boids forming ‘V’ formation with vision angle of 180 degrees and obstruction angle (a) 60 degrees. (b) 90 degrees

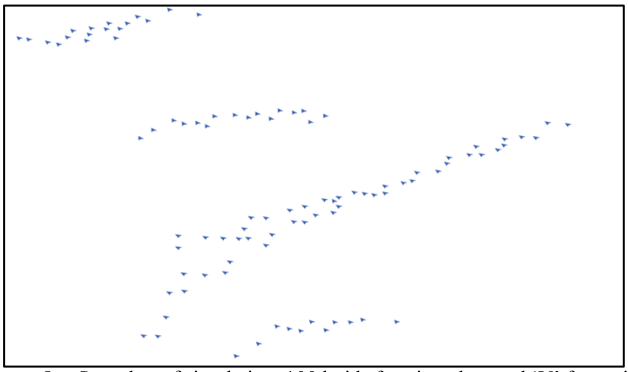

Figure 5a: Snapshot of simulation. 100 boids forming clustered ‘V’ formation with vision angle of 180 degrees and obstruction angle 60 degrees

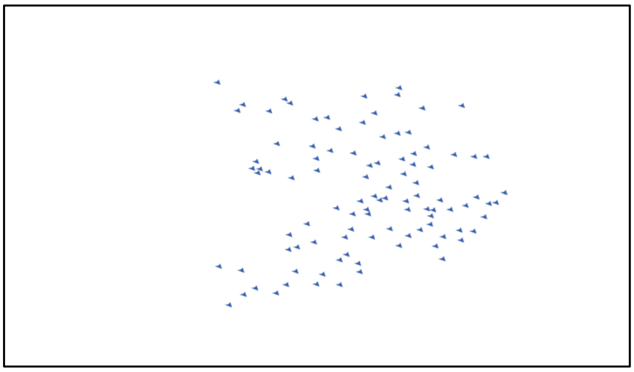

Figure 6: Snapshot of simulation. 100 boids forming clustered formation with vision angle of 180 degrees and without any obstruction angle (0 degrees).

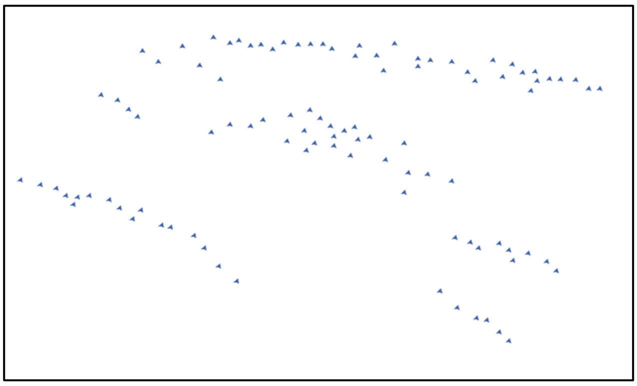

Figure 5b: Snapshot of simulation. 100 boids forming clustered ‘V’ formation with vision angle of 180 degrees and obstruction angle 90 degrees.

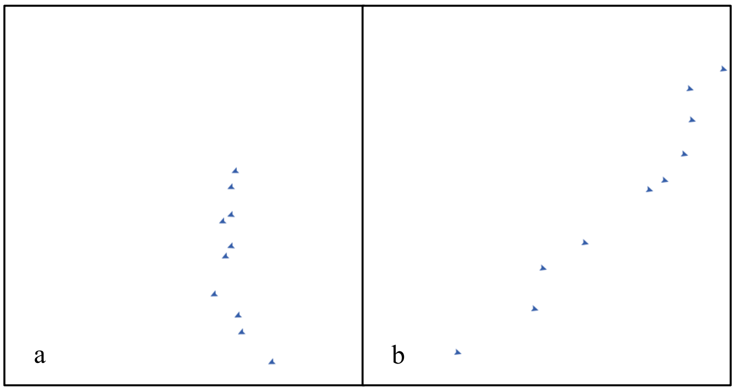

Figure 7 : Snapshot of simulation. 10 boids forming ‘V’ formation with vision angle of 180 degrees and obstruction angle 90 degrees. (a) Vision distance 5, (b) vision distance 10.

C. Vision Angle and Obstruction Angle

The introduction of the obstruction angle resulted in the formation of the ‘V’ pattern. However, the vision angle at 180 degrees with an obstruction angle of 90 degrees produced a stable ‘V’ formation. The obstruction angle of 60 degrees with a similar vision angle also resulted in ‘V’ formation; it is more compact than the obstruction angle of 90 degrees. However, increasing the vision angle while constraining boids with obstruction angle resulted in a continuous change of the flight direction of the entire flock. A high vision angle of 300 or 360 degrees resulted in cyclic rotation of the flocks, and splitting and forming groups rapidly. With an increase in the number of boids, the rotation was more rapid and no particular formation was stable. Figure 8 shows the cyclic rotation pattern emerged from the introduction of the obstruction angle in a higher field of vision.

However, the absence of the obstruction angle at wide fields of vision (270, 300 and 360 degrees) resulted in flocking making a cluster pattern in the same direction after stability (refer to Figure 9).

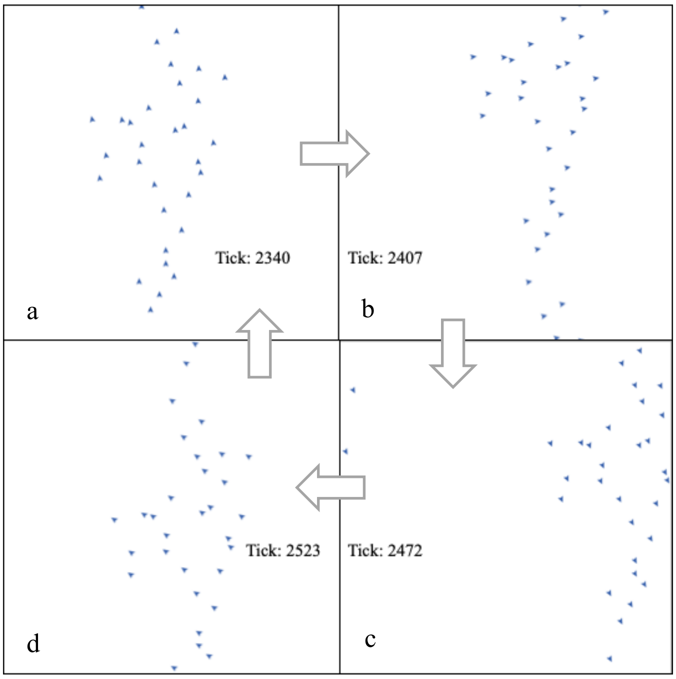

Figure 8: Snapshot of simulation. 30 boids flocking in cyclic rotation in the space with introduction of obstruction angle 90 degrees with 300 degrees of field of vision at time steps.

Figure 7 shows the average time taken for stable ‘V’ formation for 10, 20 and 30 number of boids at 180 and 270 degrees of vision ranges and obstruction angle of 60 degrees. With 30 boids, no stable formation emerged at 270 degrees due to obstruction angle; the formation broke up and the flock started cyclically changing the flight direction. Table 2 summarize the flocking patterns obtained during the simulation.

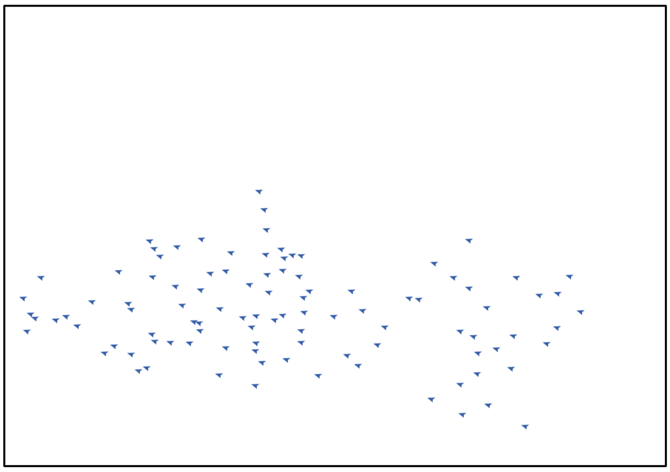

Figure 9: Snapshot of simulation. 100 boids flocking in cluster formation with wide field of vision of 300 degrees with no obstruction angle

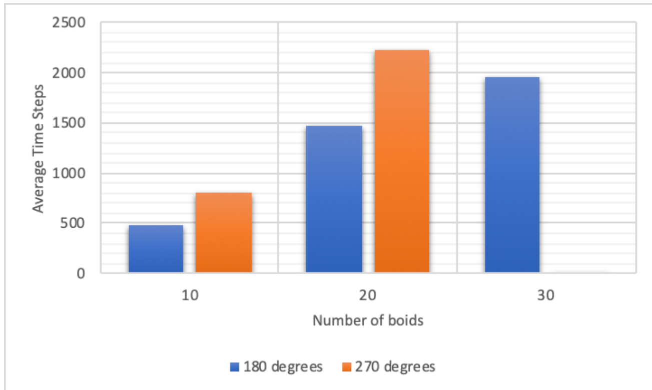

Figure 10: Time for stabilization into ‘V’ formation with 10, 20 and 30 number of boids. At 270 degrees of vision angle, no stable formation emerged for 30 boids.

TABLE 2
SUMMARY OF FLOCKING PATTERN OBTAINED FOR DIFFERENT PARAMETERS

Number of Boids	Vision Distance - Unit	Vision Angle in Degrees	Obstruction Angle in Degrees	Flocking Pattern
10/20/30	5 / 10	180 to 270	60 / 90	Compact ‘V’ Formation
10/20/30	5 / 10	270 and above	60 / 90	Laterally expanded ‘V’ formation, after stability keeps on changing direction randomly
10/20/30	5 / 10	180 to 360	0	Clustering Pattern
100	5 / 10	180 to 270	60 / 90	Wave of small group of ‘V’ Formation
100	5 / 10	270 and above	60 / 90	No stable formation; keeps on cyclically changing flock flight direction
100	5 / 10	180 to 360	0	Clustering Pattern

V. Discussions

As mentioned, one of the major limitations of the study was determining a tangible and objective evaluation criterion for boids flocking patterns. Thus, results were evaluated subjectively except the recording of the time required for stabilization of the ‘V’ pattern with the small number of boids (10, 20 and 30 boids). Within the mentioned constraints, changing the boid's perception parameters, particularly vision angle and vision distance range, produced two basic forms of patterns: ‘V’ formation and Clustering. Further refinement of perception parameters with the introduction of obstruction angles resulted in the emergence of ‘V’ formation even with a large number of birds. However, it was more apparent to find the ‘V’ pattern formation in a smaller number of boids. With a large number of boids, clustering formations were more common to emerge.

A. Effect of Number of Boids

The number of boids influences the emergence of various patterns. Formation of stable ‘one’ ‘V’ pattern is generally possible with a small number of boids in short time steps (refer to Figures 4 and 10). Increasing the number of boids gradually splits up the whole flocking concentration, producing a few small groups of scattered flocking. As shown in Figures 5a and 5b, waves of small ‘V’ formation emerge with a smaller field of vision (180 degrees) and obstruction angles between 60 and 90 degrees. However, any kind of flocking pattern becomes unstable with an increased vision angle in the existence of the obstruction angle. A concentrated and stable clustering pattern flocking is less affected by the number of the boids (refer to Figure 6).

B. Effect of Vision Angle and Distance

The vision angle and distance influence flight formation with distinct effects. With increased vision distance, in this experiment 10 units distance from 5 units, enabled the boid to see through a long-distance and consider all boids in its vision range as flockmates. Therefore, its velocity and position correction were influenced by the cumulated steering urge generated from a larger number of boids. At the same, due to increased visibility distance, the nearest neighbor could also be considered from a longer range. This resulted in laterally-extended ‘V’ formation (refer to Figure 7). This was only possible in the case of a lower vision angle such as 180 degrees when the obstruction angle was in effect. In a higher range of vision angles such as 270 degrees and above, under the constraints of obstruction angle, individual boid had an extra-wide and extended vision. This resulted in a further impact on the acceleration and positioning corrections for the boid. Therefore, ‘V’ formation was not stable. Besides, the flocking formation broke down with the continuous change in the overall flight direction. The other effect of increased vision distance was occasional breaking up of the flock to form a separate small cluster.

With smaller vision distance, compact flocking patterns were observed. The limited vision, not ignoring the minimum space separation requirement for collision avoidance, offered only a small number of boids to be considered as flockmates. Thus, splitting from the flocking formation even for a group of a small number of boids was not observed, resulting in a stable and compact formation.

Similarly, the vision angle had a significant effect on the flocking pattern emergence. Natural birds have a wide range of fields of vision. In this study, it was observed that the flocking pattern changed with an increased vision angle. Increasing vision angle from 180 degrees to 270 degrees extends the ‘V’ formation laterally with wide dispersion. This is because each boid's visual perception direction increment resulted in an all-inclusive coverage towards the sides and even at the rear (in case of 360 degrees) of its position to be considered as flockmate. To keep up to the minimum separation distance to avoid the collision, the formation extended laterally.

On the other hand, at 0 obstruction angle, meaning that when each boid had almost a circular vision (in case of 300 and 360 degrees), the clustering pattern was found to emerge (Refer to Figure 9). Increasing the number of boids had little effect on the formation of a clustering pattern.

C. Effect of Obstruction Angle

The obstruction angle appeared as one of the critical criteria for the formation of the ‘V’ pattern. Without obstruction angle, the boid attempted to position itself just immediately rear of the leading boid that results in clustering. The obstruction angle drives the boid to seek any of the sides of the preceding boid at an angle of 30 or 45 degrees (for the obstruction angle of 60 and 90 degrees respectively). The gradual repositioning of the boids to seek an unobstructed view resulted in the formation of the ‘V’ pattern. With 180-degree vision angle and 60 degrees of obstruction angle, each boid when seeking coherence, its vision got restricted to 120 degrees with a blank radius of 60 degrees as soon as it stayed at the immediate rear of the preceding boid. Driven by the urge to get an unobstructed view, it accelerated to any of the sides of the preceding boid (refer to Figure 4). This also confirms one of the important benefits of flying in ‘V’ formation for migrating birds.

However, a relative ratio of visual angle and obstruction angle is also critical for the formation of the ‘V’ pattern. With a higher degree of vision angles such as 270 degrees or higher under the constraint of an obstruction angle of 60 or 90 degrees, the boid when moved to any of the sides of the preceding boid, it received a clear vision of 270 degrees or higher. But, as soon as it received a clear vision, it started to consider the other boids in its visual angle; that again introduced another acceleration adjustment. Thus, no stable formation could be observed. Increasing the boids' number introduced a cyclic flight direction, rotating almost in the same place rapidly in the space (refer to Figure 8). It is found that the vision angle between 180 degrees and 270 degrees is suitable for forming a ‘V’ formation (refer to Figure 10). On the other hand, increasing the value of the obstruction angle beyond 90 degrees at a small vision angle resulted in lateral line formation, that is not suitable for leveraging the benefit of upwash. Therefore, the obstruction angle between 60 and 90 degrees, which can only be formed when follower boid's wingspan overlaps only one-third of the preceding boid's wingspan or less, is ideal for emergence of 'V' pattern.

For clustering pattern flocking that is observed in small birds in nature, the influence of the obstruction angle must be removed at a larger field of vision. In the absence of an obstruction angle, the boid had an almost 360-degree view of its neighborhood that resulted in compact clustering formation (refer to Figures 6 and 10). This reflects that an unobstructed view may not be a necessary condition for small birds flying in clustering pattern.

D. *Effect of Neighborhood*

The neighborhood of a boid produces the velocity and position corrections for the boid. Each boid makes two distinct assessments of its neighborhood: flockmate (close neighbor define by its visual range) and nearest neighbor. The velocity and direction corrections are calculated from the flockmates' overall speed and heading. On the other hand, the nearest neighbor provides the flight correction parameters for avoiding a collision. Change in the boid count, vision angle, distance and obstruction angle either increased or decreased the radius for which a boid defined its neighborhood. Results show that various parameters produced different extents of acceleration requests for individual boids that contributed to either formation of a stable flocking formation or breaking up the flock.

VI. Conclusions

Swarm intelligence has been drawing increasing interest in artificial systems due to its powerful and robust problem-solving capability. To understand the interplay working in the biological life and regulate the desired solution, computer-simulated agent-based modeling is a useful tool. In this work, two patterns of birds' flocking, clustering and 'V' formation, were studied by sweeping four most important parameters: population size, vision distance, vision angle, and obstruction angle. The flocking patterns were recorded and evaluated subjectively due to the absence of a suitable definition of perfect flocking. The results show that the emergence of a clustering pattern is common with a large number of boids with a vision angle between 180 and 360 degrees when no obstruction angle is enforced. 'V' formation is typical to emerge with the imposition of an obstruction angle to facilitate an unobstructed view ahead with vision angles between 180 and 270 degrees. Increasing vision distance disperses the formation of any patterns laterally. The introduction of the obstruction angle emerges as an important factor for forming a 'V' pattern as this drives the boid to choose any of the rear sides of the preceding birds. Seeking a position at the rear-oblique to the preceding bird also places the boid in a position to maximize the aerodynamic benefit of the upwash. Further study on how flocking birds negotiate obstacles with different perception parameters can provide further important insights on birds flocking formations.

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