RESEARCH ON AGENT AND CELLULAR AUTOMATA SIMULATION OF THE HERD EFFECT
/
羊群效应的智能体和元胞自动机模拟研究

Lili NIE, Fan JIAO, Tingting YANG, Zhenyu LIU *) [1]
College of Information Science and Engineering, Shanxi Agricultural University, Taigu,Shanxi/ China
Tel: 13593101646; E-mail: lzysyb@126.com
Corresponding author: Liu Zhenyu
DOI: https://doi.org/10.35633/inmateh-68-80

Keywords: *cellular automata, herd behaviour, movement rules*

ABSTRACT
To investigate the mechanism of the movement law of sheep and theoretically support the study on the herd effect, a herd effect model based on the agent and cellular automata technology is built. The law of the herd effect is defined with the use of PyCharm for simulation, based on the characteristics of the flock tending to the top sheep. The flock activity area falls into several two-dimensional cell space structures, and the grid with the cell state of "sheep" in the cell space structure is considered a type of agent. The model assumed that there are five behaviours, including standing, walking slowly, looking for the leader, random and avoiding collisions in four scenarios. A herd effect model is built, the herd behaviour is simulated, and the simulation results are compared with the actual herd behaviour trajectory. The mean square error between the calculation model and the reality is 1.025. As revealed by the results, the model exhibits effective applicability, so it can better describe the trajectory of real herd behaviour and provide theoretical guidance for the study on the herd effect.

摘要
为揭示羊群的运动规律机制，能够为羊群效应的研究奠定理论依据，构建了基于智能体和元胞自动机技术的羊群效应模型。利用 PyCharm 进行仿真，基于羊群趋向头羊的特点,定义了羊群效应规律，把羊群活动区域分割为若干个二维的元胞空间结构，把元胞空间结构中元胞状态为"羊"的网格看成是一种智能体。模型假设了四种情景下存在站立、慢走、寻找头羊、随机以及避免碰撞五种行为。构建羊群效应模型，对羊群的从众行为进行模拟仿真，并将仿真结果与现实羊群行为轨迹加以比较拟合，计算模型和现实的均方误差为 1.025，结果显示该模型具备了有效的适用性，从而可以较好地描述现实羊群行为轨迹，为羊群效应研究提供理论指导。

INTRODUCTION
Group movement refers to a biological activity in nature *(Lu et al., 2021)*. As intelligent technology of animal husbandry has been continuously updated, the simulation of the herd effect has become a research hotspot. The herd effect represents cattle, sheep and other livestock moving and foraging in groups, following the actions of the leader blindly, and following the respective other in the process. It is also referred to as group psychology, i.e., a phenomenon to consciously imitate the leader. Collective behaviour originates from the interaction between members, sheep show orderly movement in the process of flocking, and the flock naturally tends to follow the leader and walk cooperatively *(Biro D. et al., 2016)*. *Wang et al., (2019),* investigated the feasibility of using animal escape experiments to assist the verification of group simulation models. They provided some references for in-depth research on group behaviour models. *Wang et al., (2021),* built an agent model for simulating fish behaviour. The model assumes three scenarios and eight corresponding fish movement behaviours, thus laying a vital basic of data for fish activity simulation research. *Chang et al., (2011),* built a grid-based Agent group model, dividing the crowd aggregation model into exploration activities, decision-making behaviours, and actions. The Agent group model is capable of accurately simulating crowd behaviour and further studying the law of crowd aggregation. Based on the theory of cellular automata, *Toyama M.C. et al., (2006),* built an Agent-based model, explaining the negative effects of various behavioural characteristics (e.g., gender, speed, perception, herd behaviour, as well as obstacle avoidance behaviour).

---
[1] *Nie Lili, M.S. Stud.; Jiao Fan, M.S. Stud.;YANG Tingting, M.S. Stud.; Liu Zhenyu, Prof. Ph.D.*

Liu et al., (2022), provided more insights into herd behaviour on crowd evacuation, which contributes to crowd accident management. *(Wagner et al., 1997),* used cellular automata as the research engine of GIS (geographic information systems) to enhance the dynamic spatial modelling ability. According to the advantages of cellular automata simulation in studying more complex systems, it is introduced to the herd effect simulation. The herd effect is clarified by the simulation rules of the herd effect model, and the application of the herd effect in numerous aspects is explored. Through the processing and analysis of the process of the herd effect, the group movement mechanism of sheep is revealed, which lays a theoretical foundation for the study on the herd effect.

MATERIALS AND METHODS

Cellular Automata

Cellular automata (CA), proposed by von Neumann, refers to a method for simulating partial laws and partial associations. A typical cellular automaton is defined on a grid, and the grid at the respective point represents a certain cell and a finite state of motion. The change rules should be suitable for the respective cell and can be performed simultaneously, and finally form the overall evolution trend (*Chang et al., 2011*). In the CA mode, the respective cell distributed in the regular grid takes a finite discrete state, and according to the same functional law, the same changes are made according to the known local law. The evolution of a dynamic system is formed by interactions between a large number of cells.

Agent-based cellular automata modelling theory

Based on a knowledge-based system that interacts with a dynamic environment to perform tasks, an agent is capable of learning and making reasonable decisions in a dynamic environment, and automatically select actions based on task characteristics (*Safa'a Yousef Abu et al, 2021*). Similar to the human brain, Agent can not only perceive environmental information, but also make decisions. The agent can autonomously decide whether to respond to the information from other agents, i.e., the agent system can encapsulate the behaviour.

The agent model for simulating sheep behaviour

The model divides the sheep farm area under study into 20×20 rectangular grids of equal size, the respective grid point represents a set of cell space structure, and the grid points connected together constitute a group of two-dimensional space, that is, the two-dimensional cellular space structure of the sheep farm.

Sheep sensing range

To simulate the sensing range of the sheep agent, it is assumed that in the cell space, the sheep agent is the centre point, the neighbour cell radius of the sensing range is R, and the square formed by the side length is $2R$, which is the sensing range of the sheep agent, as depicted in Fig.1. The induction radius of sheep is around the body length range, and the calculation method is expressed in Equation (1).

$$R = L_f(1 + R_n) \tag{1}$$

where:

L_f—size of sheep;

R_n—random influence factor, the value ranges from 0 to 1.

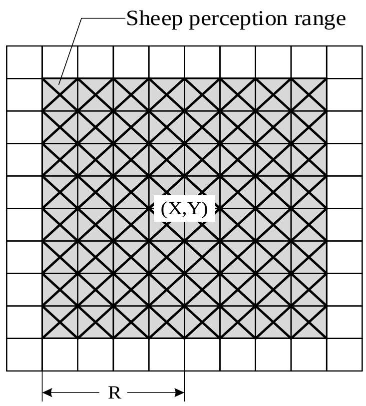


Fig. 1 – Perception range of sheep

Movement direction and step distance

The traditional Agent-CA model uses eight directions as illustrated in Fig. 2 to represent the moving direction of the Agent. Since the above motion method achieves effective results in the simulation of personnel evacuation, this experiment describes sheep behaviour through individual sheep moving direction.

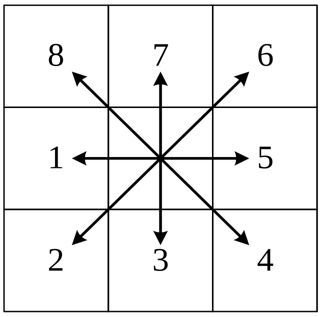


Fig. 2 – Agent movement direction of the traditional model

In this experiment, the movement of sheep in the sheep farm is expressed by combining the movement mode of sheep with the step length. To be specific, the sheep individual represents the centre point, and the square with a side length of $2\Delta_s$ is the movement range of the sheep agent. The correlation between the number of motion directions and the step distance is expressed in Equation (2).

$$n = \left(\frac{2\Delta_s}{a}\right) \times 4 - 4 \tag{2}$$

where:

n—number of directions of motion;

Δ_s—step;

a—grid side length

Gait refers to the coordination relationship between the limbs of animals in time and space during the movement process, i.e., the repetitive sequence and manner of the regular movement and stop of the respective limb. The gait cycle is a complete cycle of a certain foot movement in which the gait movement participates in the movement (*Liu, 2012*). As revealed by the result of the experiment, the average gait cycle of blue sheep walking slowly is 425 ms, the average speed of normal walking on flat ground is 53 cm/s, and the step distance is nearly 27 cm.

The step distance (Δ_s) of the sheep is obtained by Equation (3).

$$\Delta_s = 0.2L_f \tag{3}$$

Model assumptions

According to the relevant research results of group movement, the group movement is divided into four scenarios (*Wang et al., 2019*), as depicted in Table 1.

In the model, when the Agent is in the above four scenarios, it will simulate the sheep to make the corresponding movement behaviour. According to the sheep behaviour data, the corresponding sheep behaviours in the four scenarios assumed by the model are as follows:

① Standing behaviour: The behaviour of the sheep's four hooves coming into contact with the ground to support the body. The sheep agent expressed in the model remains stationary within the sensing range.

② Slow walking behaviour: a group of slow rhythmic symmetrical movements of the ewe. The sheep agent expressed in the model moves to the adjacent grid within the sensing range.

③ Looking for the leader: The sheep senses the leader's direction and moves toward the leader. The sheep agent expressed in the model moves to the most attractive grid within the sensing range.

④ Random behaviour: Since the model does not consider all the influencing factors of the flock activity, it is possible to move in a random direction during the whole flock activity. The sheep agent expressed in the model may move in any direction.

⑤ Collision avoidance behaviour: sheep keep a distance from obstacles to avoid collision. The sheep agent expressed in the model no longer moves to the obstacle.

Table 1

Scenario model assumptions

Scene number(s)	Herd behaviour	Scenario overview
1	standing behaviour; random behaviour	When the small range of activities of the leading sheep and the nearby sheep remains basically unchanged, the behaviour of the sheep is primarily standing behaviour and random behaviour.
2	slow walking behaviour; random behaviour	Sensing the movement of the approaching sheep, the sheep begin to move to the approaching sheep and move with them.
3	looking for leader behaviour; random behaviour	Sensing the movement of the head sheep, the sheep begins to tend to the head sheep, and the behaviour of the sheep is mostly to find the head sheep.
4	avoid collision behaviour; random behaviour	When recognizing that there is an obstacle around, the sheep will not move in the direction of the obstacle, and the behaviour of the sheep at this time is largely to avoid collision.

Movement rules of individual sheep

The movement rule built by the literature (*Goodwin et al., 2006*) is that the agent moves to the grid with the strongest attraction in the vicinity, and randomness is considered when the sheep behaviour rule is being established. In accordance with the response relationship of the sheep agent to the adjacent factors, the probability of the sheep agent moving to the motion area is calculated. On that basis, the final result of the movement of the sheep agent is determined.

The agent movement probability is obtained by Equation (4).

$$prob\_dir_{(D)} = P_{con}^{s}(D) \tag{4}$$

where:

$prob\_dir_{(D)}$—the possibility of the agent moving in the direction D;

$P_{con}^{s}(D)$—attraction probability to D direction in different scenarios.

In the four hypothetical scenarios, when s=1, the agent is in the scene of maintaining a small range; when s=2, the agent is in following the adjacent scene; when s=3, the agent is in the scene of following the leader; when s=4, the agent is in a collision avoidance scenario.

The calculation of the agent's perceived attractiveness probability is shown in Equation (5).

$$P_{con}^{s}(D) = \frac{\sum_{l=1}^{5} \alpha_{l}^{s}(D)}{A^{s}} \tag{5}$$

Where A^s is sum of mesh attraction weight factors in different scenarios; $\alpha_{l}^{s}(D)$ is the mesh attraction weight factor for the l behaviour in the D-th direction in the s scene, l is the behaviour, which ranges from 1 to 5, and is represented as standing behaviour, slow walking behaviour, looking for the leader, random behaviour and collision avoidance behaviour. s=1, $\alpha_2^1(D)$, $\alpha_3^1(D)$, $\alpha_5^1(D)$ are all equal to 0; s=2, $\alpha_1^2(D)$, $\alpha_3^2(D)$, $\alpha_5^2(D)$ are all equal to 0; s=3, $\alpha_1^3(D)$, $\alpha_2^3(D)$, $\alpha_5^3(D)$ are all equal to 0; s=4, $\alpha_1^4(D)$, $\alpha_2^4(D)$, $\alpha_3^4(D)$ are all equal to 0.

The sheep agent exhibits different behaviours in four scenarios, and the calculation formula is as follows:
① The effect arising from standing behaviour on the weight factor for grid attraction in all directions.

The standing behaviour is expressed in the model as when there is no movement in the agent's perception area, the sheep agent does not move to other areas.

The calculation formula is Equation (6).

$$\alpha_1^s(D_{stand}) = \alpha_{stand}(s = 1) \tag{6}$$

where:

D_{stand}—Standing direction;

α_{stand}—Attraction weighting factor for the sheep agent to move in situ due to standing behaviour in s-scenario.

② Effect of slow walking behaviour on the weight factor for grid attraction in all directions

The slow walking behaviour is expressed in the model as Agent moving to the adjacent grid within its perception range, and its expression is Equation (7).

$$\alpha_2^s(D_{near}) = \alpha_{near}(s = 2) \tag{7}$$

where:

D_{near}—Approaching the direction of movement of adjacent sheep;

α_{near}—Attraction weighting factor for walking slowly to nearby sheep;

$\alpha_2^s(D_{near})$—The attraction weighting factor that makes the agent move in the D_{near} direction when walking slowly in the s scene.

③ The effect of the behaviour of looking for the leader on the attractiveness weight factor for the grid in all directions

The behaviour of finding the leader is that Agent moves to the location of the leader in its perception area. The calculation formula is Equation (8).

$$\alpha_3^s(D_{main}) = \alpha_{main}(s = 3) \tag{8}$$

where:

D_{main}—The direction of movement to the leader position;

α_{main}—The attractive weight factor for the agent's search for the behaviour of the leader;

$\alpha_3^s(D_{main})$—In the s scene, look for the attractive weight factor that makes the agent move in the direction of D_{main}.

④ Effect of random behaviour on the weight factor for grid attraction in all directions

Random behaviour is expressed as the agent may move in any direction, and its calculation formula is Equation (9).

$$\alpha_4^s(1) = \alpha_4^s(2) = \alpha_4^s(3) = \alpha_4^s(4) = \cdots = \alpha_4^s(n) = \alpha_{ran}(s = 1,2,3,4) \tag{9}$$

where:

n—The number of moving directions of the sheep agent;

α_{ran}—Attraction weight factor for random behaviour;

$\alpha_4^s(1) \sim \alpha_4^s(n)$—Attraction weight factor for the agent to move in the direction 1 ~ n.

⑤ The effect of collision avoidance behaviour on the mesh attraction weight factor in all directions

There are attraction and repulsion effects in the interaction. When there is an obstacle in the perception range of the Agent, it will avoid collision and no longer move in the direction of the obstacle, thus revealing the repulsion effect.

The specific expression is Equation (10).

$$\alpha_5^s(D_{avoid}) = \sum_{i=1}^{5} \alpha_i^s\,(D_{avoid}) = 0(s = 4) \tag{10}$$

where:

D_{avoid}—he direction of the obstacle location;

$\alpha_5^s(D_{avoid})$—Attraction weighting factor for the sheep agent to move in the direction of D_{avoid}.

RESULTS

System accuracy test

Herding behaviour refers to one of the characteristic behaviours of crowd evacuation. The cellular automata model has been extensively used in group evacuation, and the proposed discretization concept provides an effective entry point for the simulation of real herd behaviour on the computer.

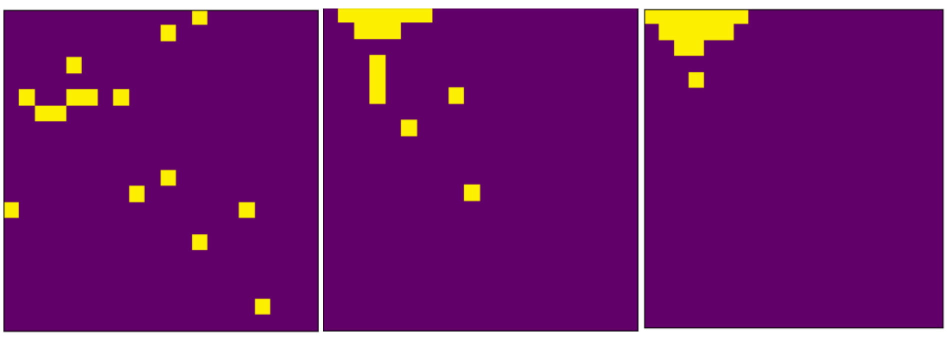
The purpose of this experiment is to study the movement state of flock in a limited space. The shooting location is a breeding farm in Baotou, Inner Mongolia, China, with an entity of 20m×20m sheep farms, 15 domesticated sheep in the sheep farm were selected as the experimental objects, and the camera is used to take pictures and videos, and observe in the experiment. In the process from disorder to order, when the flock is in a disordered and mixed state at rest, the leading sheep start to act first, then the number of groups that join the order process increases. Finally, the disordered rest phase gradually turned into an orderly feeding and exercise phase.

The aggregation process is presented in Fig. 3.

a) *b)* *c)*

Fig. 3 – The flock gathering process

PyCharm is a Python IDE that comes with a set of tools to help users improve their productivity while developing in the Python language. The experiment was simulated using PyCharm, with the environment configured as Python=3.8. A 20m×20m sheep farm area is set, twenty sheep in the area were selected as experimental samples. The coordinates of the position point in the area are (x, y) are set, and the parameter values of the model are given: random behaviour is not the main behaviour, so the attraction weight is small, and $\alpha_{ran} = 5$ is defined. The main behaviours of the flock comprise standing, walking slowly, looking for the leader, and avoiding collision. The attraction weight factor for standing behaviour is set as $\alpha_{stand} = 20$, and the attraction weight factor for other behaviours is defined as 25. Each cell represents a solid sheep. The total length of each experiment was 40 s, and the sheep gradually converged to the head through 100 training times. The trajectory results obtained by the model simulation are presented in Fig. 4.



a) *b)* *c)*

Fig. 4 – Simulation process of the herd effect

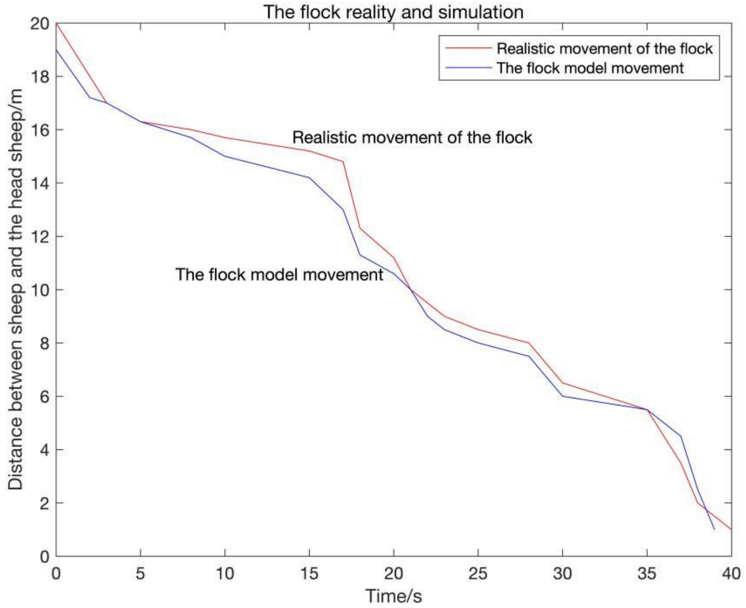


Fig. 5 – Herding reality and model simulation

The distance between the flock and the head sheep is employed as the basis for fitting the model and reality. Through the simulation of the flock model and reality as illustrated in Fig. 5, the mean square error (MSE) between the model and the reality data is obtained as 1.025. Combining the model simulation trajectories in Fig. 3 and 4 with the actual trajectories of the herd effect, the trajectories of the herds tend to be discrete to the leading sheep, and there is a low error. As revealed by the above analysis results, the behaviour of the agent-based herd imitating each other strategy is one of the internal reasons for the formation of herd behaviour.

CONCLUSIONS

In this paper, the agent and the cellular machine are automatically integrated, and a herd effect simulation model is built. The model assumes four scenarios, which consist of keeping a small range, following the approach, following the leader, as well as surrounding obstacles. There are five corresponding behaviours in different scenarios, including standing, walking slowly, looking for a leader, random and avoiding collision. The effect arising from five behaviours on grid attractiveness is analysed, and its moving rules are established by means of random process.

The simulation is performed within the range of sheep activity, and the built Agent model can directly simulate the behaviour pattern of following the leader sheep and the state of the neighbouring cells. The simulation results can reveal the movement law of the herd effect, which confirm that the built Agent model is capable of describing the movement trajectory of the herd behaviour more accurately.

This paper provides a frame of reference for studying the law of movement of biological groups through the herd effect model, which contributes to follow-up research and theoretically guides the study on the herd effect.

ACKNOWLEDGEMENT

The authors were funded for this project by the National Natural Science Foundation of China (NSFC) (No.31772651) and "Teaching and Research Management" Fund of School of Information Science and Engineering, Shanxi Agricultural University (No.XK19201).

REFERENCES

[1] Biro, D, Takao, Sasaki, T. & Portugal S. (2016). Bringing a Time–Depth Perspective to Collective Animal Behaviour. *Trends in Ecology & Evolution*, Vol. 31, pp. 550-562, Britain.

[2] Chang, Q., Dang, H. (2020). Research on Crowd Aggregation Model of Group Events Based on Grid Agent (基于网格 Agent 的群体性事件人群聚集模型研究). *Journal of Chinese People's Public Security University (Science and Technology)*, Vol. 17, pp. 71-74, Beijing/China.

[3] Lu, X., Yuan, W., (2021). Principle of Least Potential Energy in the Cellular Automata Model for Collective Motion of Fish Schools (鱼类群体运动的元胞自动机模型中的最小势能原理). *ACTA AUTOMATICA SINICA*, Vol. 47, pp. 1422-1427, Sichuan/China.
[4] Liu, Y.X., & Mao, Z., (2022). An experimental study on the critical state of herd behaviour in decision-making of the crowd evacuation. *Physica A: Statistical Mechanics and its Applications*, Vol. 595, p.127087, Beijing/China.
[5] Liu, X., (2012). The kinematics analysis of the blue sheep gait in Helan Mountain (贺兰山岩羊步态运动学分析). *Northeast Forestry University*, Heilongjiang/China.
[6] Goodwin R.A., John, Nestler M.J., Anderson J.J., Weber L., Loucks D. (2006). Forecasting 3-D fish movement behaviour using a Eulerian–Lagrangian–agent method (ELAM). *Ecological Modelling*, Vol.192, pp.197-223, U.S.A.
[7] Safa'a Yousef Abu, H., & Ibtehal, N. (2021). An Intelligent Agent Model and a Simulation for a Given Task in a Specific Environment. *American Journal of Artificial Intelligence*, Vol. 5, pp. 1-16, Saudi Arabia.
[8] Toyama M.C, Bazzan A., & da Silva R. (2006). An agent-based simulation of pedestrian dynamics. *Autonomous Agents and Multiagent Systems*, pp. 108-110, Brazil.
[9] Wagner D.F., (1997). Cellular Automata and Geographic Information Systems. *Environment and Planning B: Planning and Design*, Vol. 24, pp. 219-234, U.S.A.
[10] Wang, J., Liu, T., Liu, Z., Xu, H., Zhong, Z., Chai, Y., (2019). Experiments on Animal Evacuation Behaviours and Crowd Virtual Simulations: A Review (动物群体逃生行为实验和群体虚拟仿真研究综述). *Journal of Computer-Aided Design & Computer Graphics*, Vol. 31, pp.218-228, Ningbo/China.
[11] Wang, J., Qi, Z., Sun, S., Zhang, C., (2021). Simulation of fish behaviour in fish pass based on agent and cellular automata (基于智能体和元胞自动机的鱼道内鱼类行为模拟). *Transactions of the Chinese Society of Agricultural Engineering*, Vol.37, pp. 239-248, Hebei/China.