AKADÉMIAI KIADÓ

Multi-agent simulation of pedestrian activity in historic district

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ABSTRACT

Multi-agent simulation has received a lot of attention in recent years as an emerging design method. To improve the accuracy of the simulation results, the authors provide an optimization scheme that combines multi-agent simulation and visibility graph analysis. Investigate how to improve forecasting accuracy through model optimization.

KEYWORDS

multi-agent simulation, pedestrian dynamic simulation, visibility graph analysis, renovation design

1. INTRODUCTION

1.1. Research background

The appearance of cities is changing dramatically in tandem with the development of society and economy. In China, the conventional urban paradigm of "row placement of low rise buildings" has been replaced by the more efficient spatial model of "solitaire placement of high rise buildings" [1]. The transformation form of mass-demolishing mass-construction has produced positive results in the early stages of development, greatly improving the living environment, but this extreme method destroys the city's historical characteristics and is unsuitable for historical district renovation [2]. Historic districts are gradually abandoned by society and become urban fissures that hinder urban development. With the evolution of urban concepts in recent years, the development of Chinese cities has shifted from an emphasis on number to a focus on quality. As a result, historical districts have received more attention and have become a key factor for assessing urban quality. The renovation should give the space new functions while still protecting historical elements, reviving the area's energy, and realizing the history-present symbiosis. Furthermore, as a public area with shared functions, the historic district's reconstruction should be directed by the public's current and future demands. The essence of public activities is traffic behavior, and movement, as a dynamic link in the behavior system, is critical to comprehending the activity space of historic districts [3]. Researchers need to combine current emerging technologies and concepts to build simulation models for studying pedestrian behavior in historic districts to guide future renovations.

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1.2. Multi-agent simulation

The processing capacity of the high-precision analytical model is limited, making it impossible for researchers to solve the original model directly. As a result, Multi-Agent

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Simulation (MAS) is required to accomplish complex simulation procedures. MAS is the use of computers to artificially simulate things to offer a basis for decision-making. In the simulation process, multiple agents act autonomously, all the agents are updated asynchronously in parallel, and the whole system changes dynamically as time progresses [4]. It can build a prediction model using information from some samples, successfully overcoming the problem of excessive computation and improving model optimization and cross-professional software integration. When designing urban open spaces, pedestrian simulation is always considered a MAS that can be effectively used to lead the initial design of the project [5]. Pedestrian simulation in the macro direction is primarily utilized in urban planning, whereas pedestrian flow simulation, evacuation simulation, and building evaluation are primarily used in the micro direction. Penn and Turner [6] proposed that pausing and congestion can influence the dynamic simulation of agents based on the Visibility Graph Analysis (VGA) space syntax theory. Turner [7] also introduced a dynamic agent model that evaluates the aggregation ability of spaces from the visibility of the built environment. The MAS model developed by Moulin in 2003 [8] was used to study pedestrian behavior in urban.

1.3. Development issues and directions

The characteristics of MAS, a self-organizing complex system, are consistent with the decentralization of crowd activity. As the degree of simulation increases, the number of factors in the model also increase, which might lead to greater instability in the model. Facing the complex features in the environment, the MAS model is not perfect. For example, the authors have demonstrated through the paper that space syntax theory plays an important role in analyzing the laws of urban spatial historical changes, but a single mathematical model is only suitable for macro analysis. For historical district analysis, the accuracy of space syntax simulation is low. After that, in order to improve the simulation accuracy, the authors constructed a pedestrian model based on visual simulation, which has more influencing factors and deeper arithmetic rules. At the same time, the shortcomings of this model are also obvious: the research emphasizes the relationship between behavior and vision, so that the model must be deeply bound to the building facade, while 3D simulation reduces the convenience and extensiveness of the model's use. In addition, more complex models tend to be more difficult to interact with other MAS, resulting in low optimization efficiency and simulation accuracy. Therefore, in this study, it is necessary to build a pedestrian model with high accuracy, convenience, and cross-domain linkage to evaluate the historical districts.

2. DESIGN METHOD

2.1. NetLogo simulation model

NetLogo is a multi-agent programming language and modeling platform for simulating natural and social phenomena. It can control thousands of agents at the same time, effectively simulating the behavior of micro-individuals and macro-patterns, as well as the relationships between them. The software is convenient, and researchers can complete model programming and simulation running on the official website. It consists of three main modules: turtles, patches and observers. Dynamic agents in the software, called turtles, play the role of pedestrians in the simulation. Patches are small squares formed after a 2D plane is divided by an orthogonal grid, which is the background of the agent activity. The observer is the manipulator that controls the turtle and the patch, and can temporarily change the parameters during the simulation process, which is beneficial to the correction of the model operation.

2.2. Modeling scheme

This pedestrian activity MAS developed by the authors based on the NetLogo platform. The introduction of its concept and operation rules can provide reference.

2.2.1. Patches.

- Import: Import the site plan into NetLogo;
- Scale: Each patch represents the breadth of a human being, and as an adult moves forward 1.2 m per second on average, the agent loops three times to represent the distance the pedestrian has moved in one second;
- Area division: Divide different areas by changing the color of patches, including: block entrance, activity area, shop entrance;
- Obstacles: NetLego cannot create objects, it is required to identify obstacles by changing the color of patches and to lessen the agent's tendency to move in these places by pheromone;
- Target: The agent's activities are focused on the exit of the historical area and the store's entrance. These patches must be given a high pheromone so that they will be the target;
- Pheromone: Pheromone is an important factor connecting agent and environment, agent and agent, and it plays an important role in optimizing the model. In classic ant model, it uses pheromones to simulate the behavior of ants looking for food. The ant moves randomly until it detects a chemical "smell" and then moves towards a higher concentration of the smell. When an ant finds food, it releases this chemical smell. As more ants followed the smell trail to food, the smell trail itself was reinforced, and this kind of smell that can optimize the behavior of ants is pheromone [9].

2.2.2. Turtles.

- Generation: The researcher must ensure that the agent only hatches at the entrance and set a threshold to limit the number of spawning;
- Activity: The turtle must assess if the next patch is an obstacle or the boundary of the area before making each step. If so, it will turn; if not, it will move as normally.

All operations are performed simultaneously and affect each other;
- Direction selection: In order to provide a more realistic impact, the agent will rotate in two different situations: small angle random turning of regular movement and avoid obstacles;
- Vision: Set the agent's vision capabilities so that they move towards the target points in view, reducing the frequency of the invalid rotation;
- Disappear: The agent dies at the destination;
- Path: Record the movement trajectory of each agent for comparative study.

3. CASE STUDY

3.1. Site introduction

This paper takes the historical district of Minzhu Road as the research object to verify the accuracy and applicability of the model. Minzhu Road is located in Zhanjiang City, China. The district is mainly composed of 4 streets and 8 entrances (Fig. 1). The buildings in the area are mainly divided into 3 categories. Qi-lou buildings are mainly in Nanyang style, and often several or more than ten buildings are adjacent to each other, forming a staggered or continuous interface effect. European-style buildings are mainly public buildings and churches. In addition, there are a large number of high-rise residential buildings built in the 1980s and 1990s, which occupy a large area and are monotonous in form. The buildings in Minzhu Road historic district can reflect the social production and living conditions of the city in different historical periods. In addition, the construction, and engineering techniques of these buildings are of high research value.

3.2. Pedestrian path record

At the beginning of the study, the authors used video recording and personal tracking methods in the pedestrian district of Minzhu Road, and selected 16 pedestrians from 8 entrances of the block as subjects to record pedestrian activity paths, including passing pedestrians and tourists (Table 1). Each subject carried a miniature action camera to capture their sight history, and the researcher would follow after the person and record their movements using mobile phone video. The collected behavioral data serves as the basis for building a simulation model, and the movement trajectory can be compared with the simulation results to evaluate the accuracy of the pedestrian simulation. Recording experiments follow these rules:

- The active area is divided by a 1.2 m wide square grid, used to record the movement paths;
- Turning directions are simplified to 8 directions;
- Subjects need to tell researchers what factors lead to changes in movement;
- The experiment ends when the recorded subject enters the store or reaches the exit of the area.

3.3. Path analysis

After analyzing the collected pedestrian trajectories, the following contents were found:

First, there are a large number of turns at the intersection of Heping Road and Minquan Road. Pedestrians here are more likely to choose to turn than to continue moving in the original direction. The authors suspect that this is due to the width of the intersection. In contrast, the intersection of Minzu Road is obviously wider than the intersection of Heping Road and Minquan Road. Pedestrians in the open space can fully obtain the surrounding environmental information, which is more conducive to maintaining the previous activity mode. But pedestrians in unfamiliar narrow spaces need to turn to obtain more useful information. Therefore, at some small intersections, pedestrians who are not familiar with the environment will turn in order to obtain more new environmental information.

Second, the authors found that pedestrian activity paths on Minquan Road and lateral road are mainly concentrated

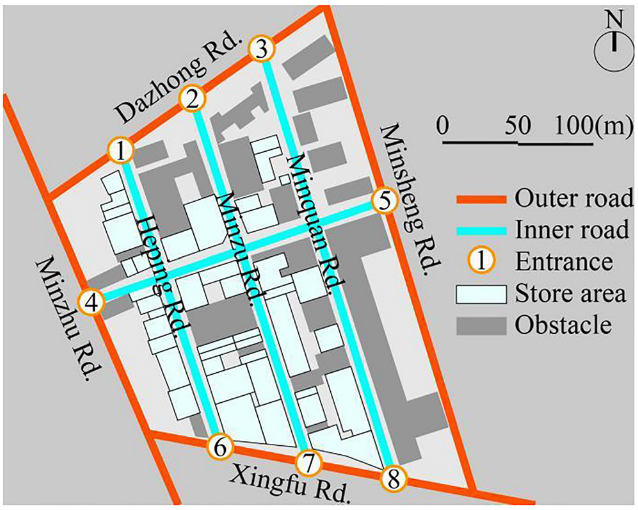

Fig. 1. Historical district plan (*Source*: drawn by Authors)

Table 1. Information record (*Source*: drawn by Authors)

Basic information			
Name	Wang Qian	Gender	Female
Role	Resident	Age range	☐ 7–15
Purpose	☑ Traffic		☑ 16–45
	☐ Shopping		☐ 46–75
	☐ Travel		
	☐ Other		
Activity record			
Start	Minquan Rd. south entrance	End	Lateral road east entrance
Turn position		Influencing factors	
Middle section of Minquan Rd.		Approach the corner early	
Kindergarten entrance		Avoid the kindergarten crowds	
Intersection of Minquan Rd.		Feel more secure	
Near the block exit		Walk towards the destination	

in the middle. Since the two roads are narrow, pedestrians can effectively receive the surrounding environmental information by walking in the middle of the road. The surrounding residents who use traffic as their activity usually show this characteristic. In addition, there are a small number of pedestrians swinging forward on Minquan Road and lateral road, and they are usually foreign tourists. The authors believe that this is related to the irregular distribution of historic buildings and high-rise residential buildings on these two roads. Tourists are more likely to be attracted by historical buildings.

The above view is evident in the activity path on Heping Road. The west side of Heping Road is composed of historical buildings, while the east side is high-rise buildings. The activity path will be obviously biased towards the side of the historical building. The authors suspect that it is caused by subconscious behavioral habits. However, in some road sections, some pedestrians will concentrate on one side even when they are retrograde on the left side, which cannot be explained by behavioral habits. The authors believe that huge high-rise residential buildings will more easily interfere with pedestrians collecting information, while the exquisite architectural structures and decorations in historical buildings convey rich visual information will be more attractive (Fig. 2).

There are three key factors in using programs to simulate pedestrian activity: space, people, and event. Commonsensically, an individual who attempts to get familiar with some strange environments, such as figuring out the route to unfamiliar places, is inclined to get to nodes that provide with a greater perspective of overall situation [5]. The activities of pedestrians are affected by the amount of potential environmental information. In a fixed environment, pheromone gradients can be used to reflect different amounts of visual information in the real place to influence the agent's activities. How to interfere with the occurrence of events through pheromones in the simulated environment will become the key research content.

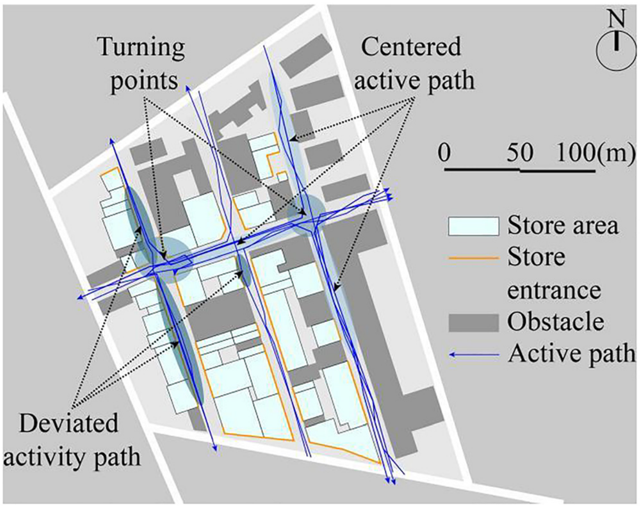

Fig. 2. Activity path (*Source*: drawn by Authors)

4. MODEL CONSTRUCTION

4.1. Wanderer's turning angle

During the simulation, researchers need to compare different simulation results by changing the parameters. The basic simulation environment parameters are all 0 and the number of agents is 50. The simulated paths shown by the MAS are all straight lines when the angle is 0°, which does not conform to the actual behavior. The simulated route has a slight wiggle when the angle is 10°. The agent appears to wander near the block's entry at 30° and 60° (Fig. 3). Angle 10° is more plausible.

4.2. Visual range

The authors next analyze the influence of various visual factors using 10° Wanderer's turning angles. Visual depth and visual angle are two of the controlling factors of visual range. When the visual angle is set to 60°, the agents' field of view is limited and they must turn to get information. As a result, the active path will display a number of illogical twists and cause agents to gather at the block entrance. At 90° the simulation results are much enhanced. The pedestrian path is clear, there are less irrational twists, and the route is no longer centered at the block entry at 120°, which is the most probable option. At 180°, the range of received information

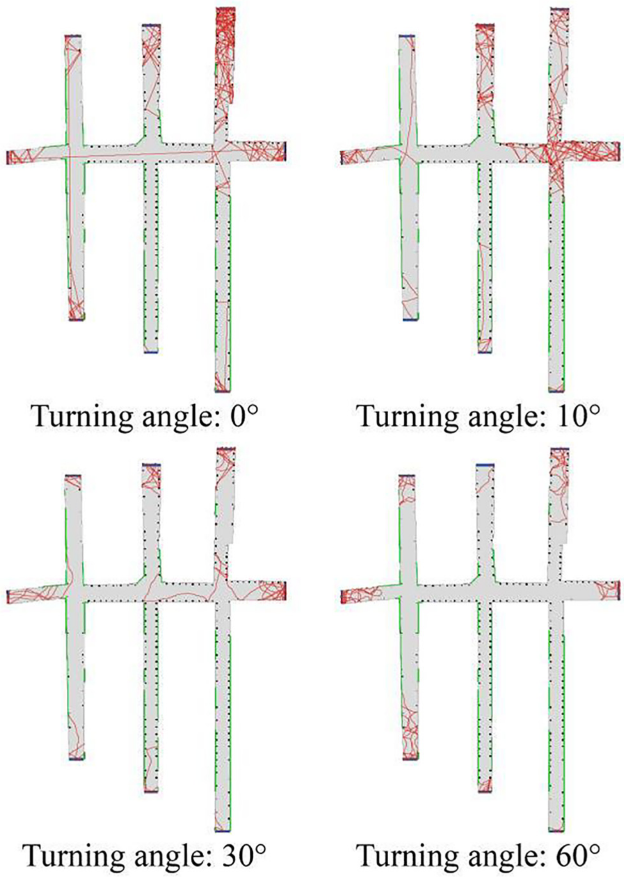

Fig. 3. Wanderer's turning angle (*Source*: drawn by Authors)

is too broad, leading the agent to be easily attracted to the environmental data at the entry and unable to go ahead, which results in the aggregation of agent activity once again (Fig. 4). According to the rules of human vision, the maximum effective viewing angle for humans is 120°, whereas the comfortable viewing angle for people is 60° [10]. When all other parameters are held constant in the research of visual depth, the default viewing angle is 120°. Agent aggregation occurred at 6 and 20 m, which produced the best route simulation results at 10 and 16 m (Fig. 5).

4.3. Turning angle of the target

The search target's turning angle was changed while the other parameters remained the same. At 30°, the agent's activity path is relatively dispersed, and it is difficult to form a line that is consistent with the real pedestrian activity law, according to a comparison between the simulation results and the recorded pedestrian activity path. The greatest results can be achieved at 60°, which can roughly depict pedestrian preferences in particular road segments and demonstrate that when confronted with an unexpected turning point, pedestrians are more used to turning than proceeding straight. At 90° and 120°, there are many unreasonable twists and inflexible broken-line routes in the simulated path (Fig. 6).

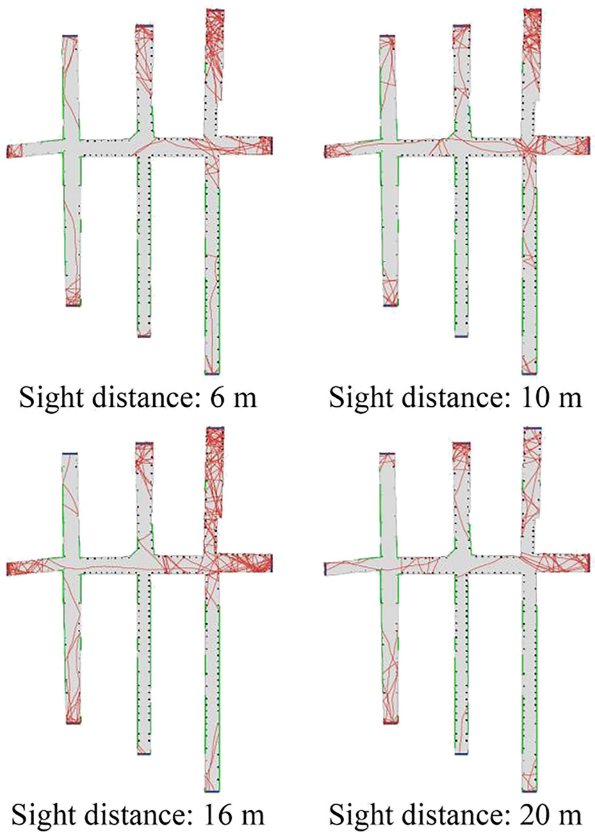

Fig. 5. Visual depth (*Source*: drawn by Authors)

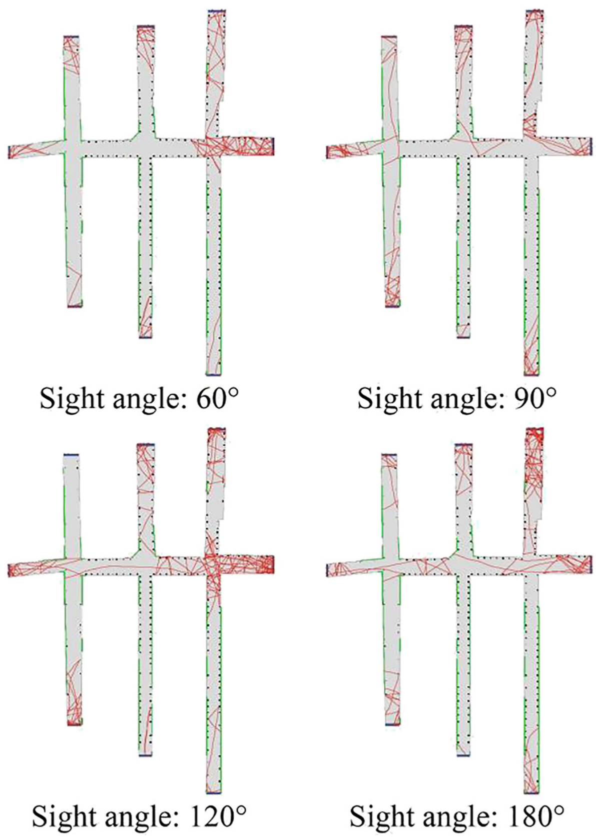

Fig. 4. Visual angle (*Source*: drawn by Authors)

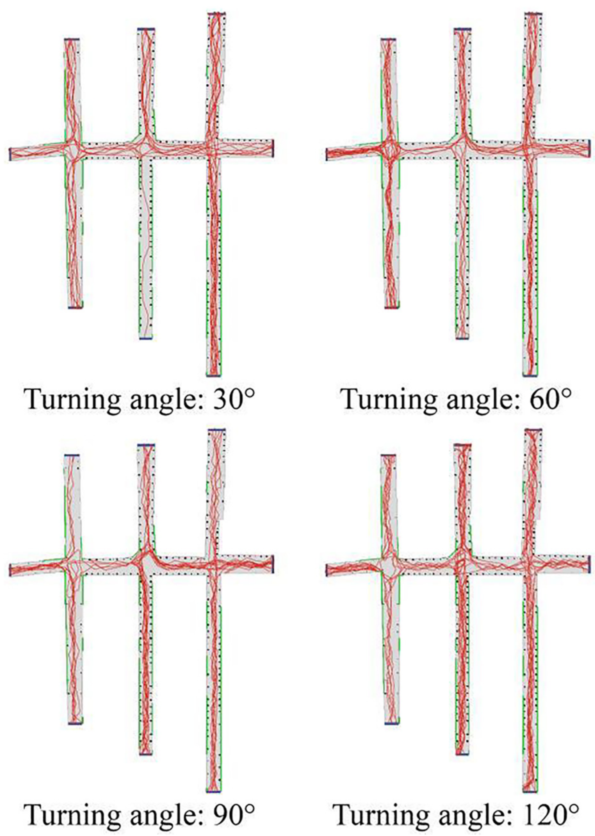

Fig. 6. Turning angle of the target (*Source*: drawn by Authors)

4.4. Model optimization

In this project, the authors first identified the useful view regions (block entry, activity space, store interior) in AutoCAD. To construct the VGA, load the plan into the depthmap program. The acquired view-shed analysis map only requires to keep the active space portion, and it needs to be turned into a gray-scale picture to lessen interference from the complex color of the VGA to the MAS. Lastly, import the VGA and MAS graph into NetLogo for simulation (Fig. 7).

For the purpose of examining whether VGA affects MAS, the authors used two viewing angles of 60° and 120°. When these two groups are compared, it is clear that the depth map achieves more precise route guiding since it further refines the patches' gravity through the pheromone gradient. The simulated pathways show features of an equal distribution when the viewing angle is 120°, which is not consistent with the circumstance under investigation. Better results can be obtained with a 60° viewing angle. Fig. 6 and Fig. 8 can be compared to show how MAS with VGA guiding streamlines the crowd moving route and almost removes the majority of redundant turning swings. More importantly, authors produce a structure resembling the activity path captured in the site survey through simulation, demonstrating that VGA can successfully optimize the MAS algorithm after entering parameters that follow human observation and activity laws into the model.

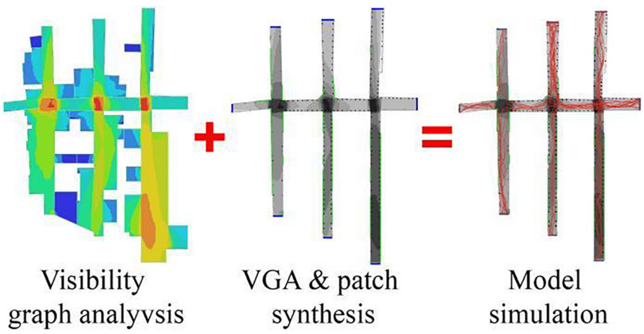

Fig. 7. VGA and MAS (*Source*: drawn by Authors)

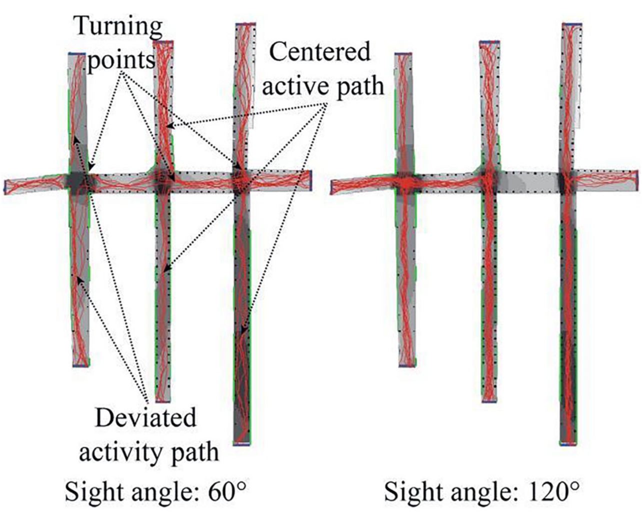

Fig. 8. Optimized MAS (*Source*: drawn by Authors)

5. CONCLUSIONS

Through research, the researchers investigated the pedestrian activity in the Minzhu Road historical district. The features of pedestrian activity in the area were identified after the data was analyzed, and the hypothesis that environmental pheromones may have an impact on pedestrian activity was put forth. The goal of the subsequent study was to build an effective and realistic multi-agent model of pedestrian routes that reflected reality while also having influence parameters (number of agents, moving speed, turning angle when wandering, field of view, turning angle for finding targets) that were consistent with the basic rules of actual pedestrian observation and activity. The researchers developed the fundamental model algorithm by the several comparison tests and generally identified the basic set of relevant influencing parameters. The authors utilizes the depth map to further improve the gravity in the patches using the pheromone gradient and realizes more precise route guidance because the simulation results at this stage are still unable to predict the behavior of people. This research shows that it is possible to use space syntax to enhance the MAS of urban space, and the improved MAS has the advantages of convenience, rationality, and accuracy.

In addition, the current development model, which established the definition of pheromone, will be extremely beneficial for future research since it will assist with the transition from design analysis to design generation. The automated creation of pavement and canopy designs for streets will be a new application of this technology.

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