Accelerating agent-based emergency evacuation planning using a knowledge database based on population distribution regularity

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Abstract

Developing optimal evacuation plans based upon agent-based evacuation simulation can be dramatically time consuming. To shorten the computation time, this study develops a knowledge database storing evacuation plans for typical population distributions generated by mobile phone location data. Then we use the knowledge database prepared offline to accelerate the real-time processes searching for near-optimal evacuation plans. Our case study demonstrates that the proposed approach can reduce the computation times by the average of 84.6%, meanwhile guaranteeing an acceptable near-optimal solution.

Keywords: agent-based model, emergency evacuation, knowledge database, mobile phone data, population distribution.

1. Introduction

Emergent hazards in densely populated areas often lead to great loss of life. To develop more efficient and effective emergency evacuation plans is central to reduce such life loss. Computer-based evacuation planning often includes two main parts: evacuation process simulation and search for the optimal evacuation plan. Because agent-based simulation supports representing interactions among individuals and between individuals and their environments, it has become a major approach to simulating evacuations where spatial–temporal dynamics and individual conditions need attention such as congestions (Bonabeau 2002, Pan 2007, Chen and Zhan, 2008, Shi et al. 2009). However, it often becomes computationally demanding when there involves large-scale evacuees. Moreover, searching for the optimal evacuation plan involves comparing combinations of evacuees, evacuation paths, and refuge selections, which often creates an NP problem. Although many heuristic algorisms have been used to search for the near-optimal solution, such as ant colony optimization, simulated annealing, and genetic algorithm, the increase of evacuees also can significantly expand the searching space. Therefore, developing evacuation plans based upon agent-based simulation can be dramatically time consuming. Efficient solutions to evacuation planning will address the need for timely response in urgent situations.

Some researchers leverage the power of parallel computing to speeding up agent-based simulation (Gong et al. 2013), while some use knowledge-guide heuristic algorithms to shorten the computation time of generating near-optimal solutions (Yin et al. 2012, Liu et al. 2013). This study focuses on obtaining the near-optimal solution and shortening the searching processes. Because a population distribution serves as a critical input to evacuation planning, this study aims to use the hourly regularity of population distributions to develop a knowledge database storing evacuation plans for typical situations, thus reducing the computation time of generating near-optimal evacuation plans using agent-based simulations.

2. Problem Definition

Because emergency evacuation situations vary a lot, to demonstrate the proposed approach, this study designs an evacuation scenario. It focuses on outdoor urban spaces mainly occupied by pedestrians. The evacuation objects are human beings. The planning objective is to minimize the evacuation clearance time. The inputs include an evacuation area, a population distribution in this area, and refuge locations. The outputs include an assigned refuge and an evacuation path for every evacuee. It also assumes this area is covered by mobile phone signals. The population distribution can be real-time estimated by mobile phone signals. The evacuation plan for each individual can be sent by mobile phone.

3. Methodologies

3.1 Framework design

As fig. 1 illustrates, based on an agent-based evacuation simulation model, this study applies a genetic algorithm (GA) to search for the near-optimal evacuation plan with evacuation clearance time as the optimization objective. In the offline environment, we develop a knowledge database of evacuation plans by calculating the near-optimal solutions based on typical population distributions of every hour. In a real-time situation, with the given population distribution in a disaster event, we search the typical population distributions which best match the given population distribution in the knowledge database. Then we use the evacuation plan of the best match to initially seed GA. This initial seed is supposed to significantly speed up to a convergence compared with a random seed.

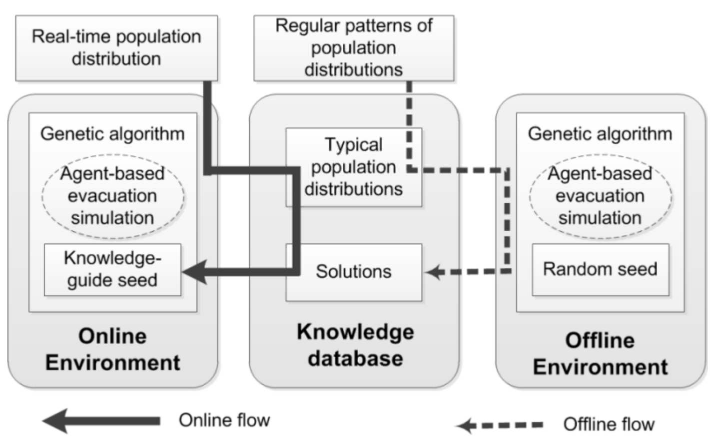

Figure 1. A framework of using a knowledge database to accelerate emergency evacuation planning.

3.2 Using mobile phone location data to generate population distribution regularity

Although people move across urban space, usually the changes of population distribution in an urban region over a 24-hours period stay stable. A large-scale mobile phone location dataset offers a reliable source to estimate change patterns of population density over a 24-hours period. Combined with total population in census data and the sampling rate of the mobile phone dataset, the regular patterns of population distributions in a region over a 24-hours period can be estimated. Since the spatial resolution of mobile phone location data is a base station, this study uses base stations as the spatial units of a population distribution.

3.3 Simulating evacuation with an agent-based model

The evacuation path for every evacuee is assigned by the shortest distance path between one's start location and selected refuge. It is calculated by the Dijkstra algorithm based on a path network in a given area. For an evacuee's motions, this study applies the concept of reciprocal velocity obstacles (RVO) to an agent-based model (van den Berg, 2008). The RVO concept has an advantage in simulating collision-avoidance among multi-agents, which is suitable for crowd simulation.

3.4 Searching for a near-optimal evacuation plan

Given n base stations in an evacuation area and m refuges, there are $n \times m$ evacuation paths. In the GA-based evacuation planning, each solution candidate is represented by a chromosome with n genes. Each gene represents an evacuation path from a base station to a refuge. The fitness value of evacuation clearance time is calculated by the agent-based simulation.

4. A Case Study

4.1 The study area, data sources, and test settings

This study takes the Huaqiangbei business district as the study area, a region with the highest population density in Shenzhen City, Guangdong Province, China (fig. 2). The mobile phone location dataset records a user's connected based station ID for every 0.5~1 hour, and covers 760 million users. For test purpose, the mobile user traces of a weekday together with the census data are used to generate the typical population distributions for each hour of a day (fig. 3). Four refuges are set at the four corners outside of the evacuation area. We then develop a knowledge database of evacuation plans by searching for the near-optimal evacuation plans using typical population distributions over a 24-hours period. Fig. 4 and fig. 5 visualize the refuge arrangement and the simulated evacuation process based on the population distribution of 8:00am.

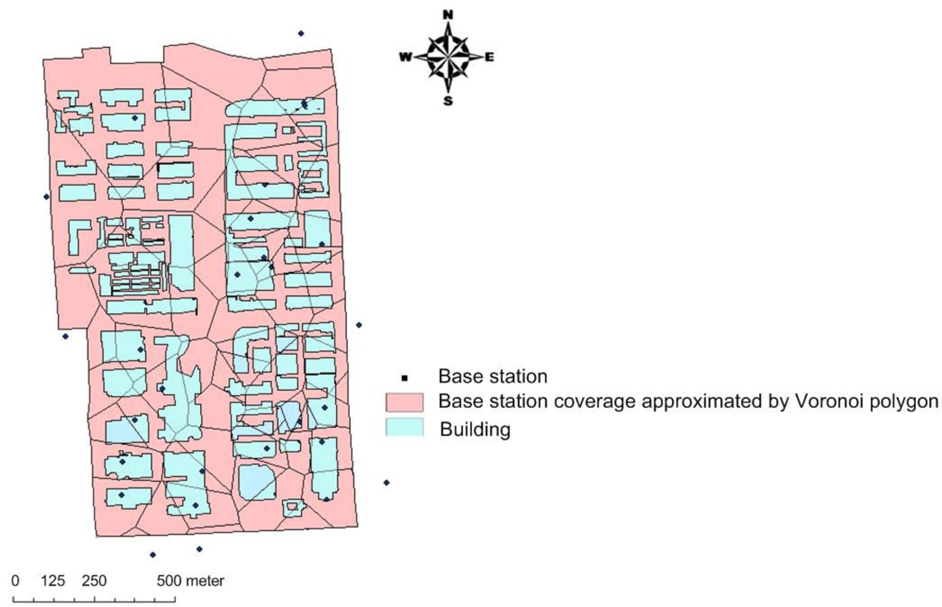

Figure 2. The study area.

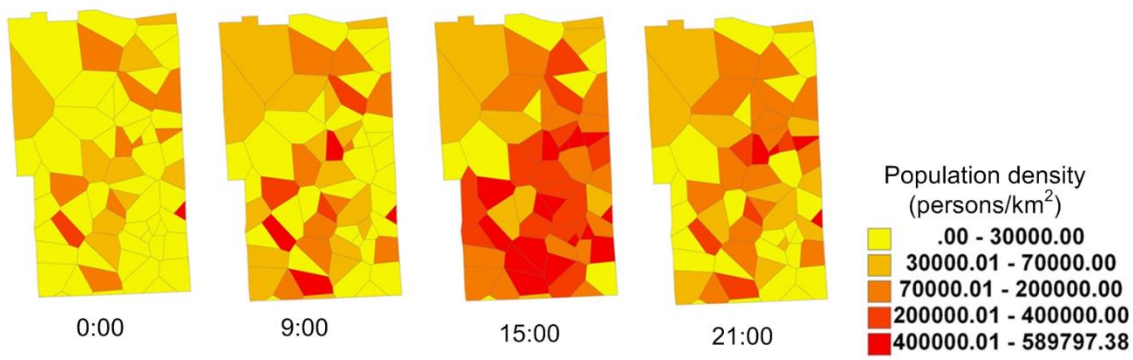

Figure 3. Population density distributions in study area at different time.

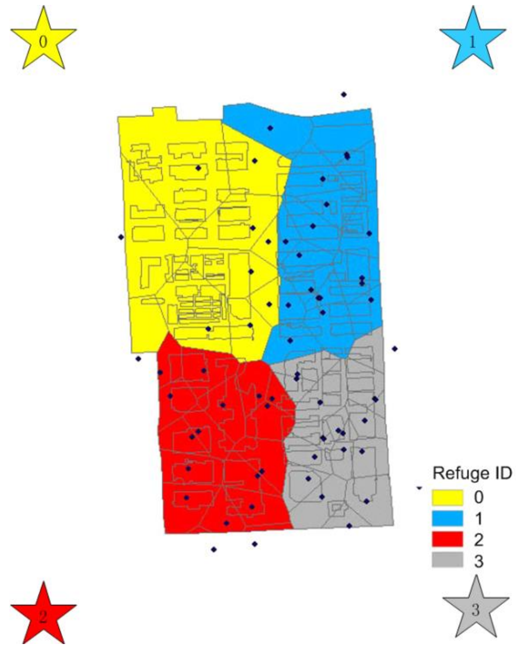

Figure 4. The optimal refuge arrangement for the population distribution of 8:00am.

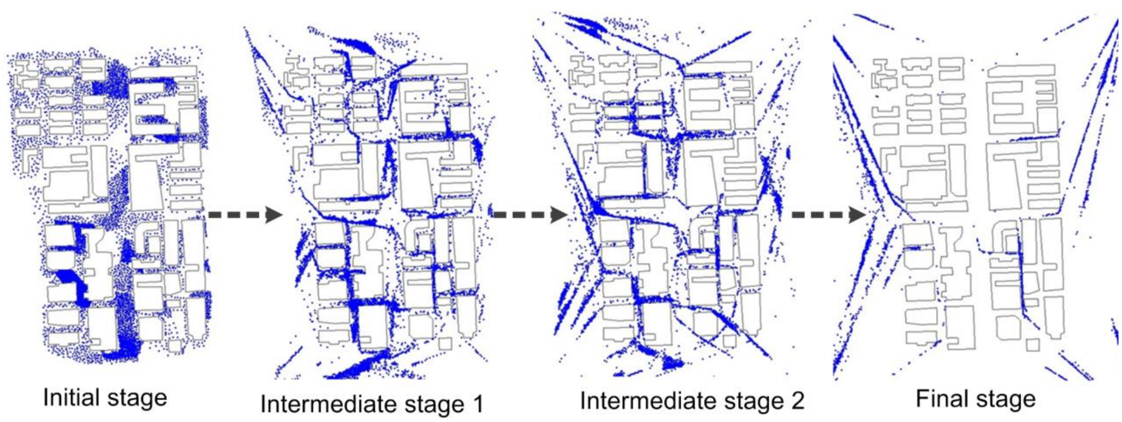

Figure 5. The simulated evacuation process using the population distribution of 8:00am.

4.2 Result analysis

We design six experiments and conduct tests on a common PC, with an Intel(R) Core(TM) i3 CPU M390 @ 2.67GH and ram memory of 4GB. We assume an emergent event happens at 8:30, 12:30, 15:30, 18:30, 21:30, and 0:30, and compare the computation times of generating evacuation plans with and without the help of a knowledge database. As table 1 shows, based on the six experiments, the knowledge database can reduce the computation times by the average of 84.6%, with an average fitness value loss of 0.82%, which can guarantee an acceptable near-optimal solution.

5. Conclusion

The proposed approach in this study can significantly improve the efficiency of agent-based evacuation planning. With the rapid development of human sensor data collection and analysis, estimating a more accurate population distribution will become easier in the future. Thus the proposed approach of developing a knowledge database based on population distribution regularity will provide a more feasible alternative solution for evacuation planning in practice.

6. Acknowledgements

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7. References

Bonabeau E, 2002, Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences*, 99(3): 7280-7287.

Chen X, Zhan FB, 2008, Agent-based modelling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies. *Journal of the Operational Research Society*, 59(1): 25-33.

Gong Z, Tang W, Bennett DA and Thill JC, 2013, Parallel agent-based simulation of individual-level spatial interactions within a multicore computing environment. *International Journal of Geographical Information Science* , 27(6):1152–1170.

Liu Y, Yuan M, He J and Qian J, 2013, Model of land use spatial optimization based on a knowledge guide genetic algorithm. *Proceedings of the 12th International Conference on GeoComputation*, Wuhan, China.

Pan X, Han C S, Dauber K, Law KH, 2007, A multi-agent based framework for the simulation of human and social behaviors during emergency evacuations. *Ai & Society*, 22(2): 113-132.

Shi J, Ren A and Chen C, 2009, Agent-based evacuation model of large public buildings under fire conditions. *Automation in Construction*, 2009, 18(3):338–347.

Yin, L, Shaw SL, Wang D, Carr EA, Berry MW, Gross LJ and Comiskey EJ, 2012, A framework of integrating GIS and parallel computing for spatial control problems --- A case study of wildfire control. *International Journal of Geographical Information Science*, 26(4): 621–641.

van den Berg J, Lin M and Manocha D, 2008, Reciprocal velocity obstacles for real-time multi-agent navigation. *Proceedings of IEEE Conference on Robotics and Automation*, Pasadena, CA, USA, 1928–1935.

	Time of an emergent event	Population	Using a knowledge base?	Fitness value: Clearance time (min)	Computation time (min)	Improvement in fitness value	Reduction of computation time
Test 1	8:30	6245	Yes	59	183	-25.5%	83.8%
			No	47	1127		
Test 2	12:30	19606	Yes	185	372	-3.3%	84.6%
			No	179	2416		
Test 3	15:30	23164	Yes	223	392	-5.2%	85.3%
			No	212	2659		
Test 4	18:30	17074	Yes	164	356	11.4%	86.5%
			No	185	2645		
Test 5	21:30	6839	Yes	65	281	12.2%	84.9%
			No	74	1856		
Test 6	0:30	3644	Yes	34	150	5.5%	82.9%
			No	36	873		
Average change						-0.82%	84.6%

Table 1. Comparing computation times and the best fitness values with and without the help of a knowledge data