

People Movement Simulation in Public Space and Its Application to Robot Motion Planner Development

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Abstract:

This paper describes people movement simulation in public space such as shopping centers and cafeteria. We decompose people movements into global and local ones, and make a model for each of them. The global movement corresponds to following a route from the current position to the destination, and is represented by a path on a spatial network whose nodes are defined as divided regions of the whole environment. The local movement is the behavior that a person avoids surrounding people and obstacles, and is modeled by a potential method. We also model the behaviors specific to the cafeteria, such as queuing and the search of free seats. As an application of the simulator, we developed a path planning simulation environment by combining the simulator and a path planner. We performed various simulation experiments on people movement and robot path planning. Experimental results show the effectiveness of the simulation.

1. Introduction

There is an increasing demand for robots which can help people in their daily life. Such a *personal service robot* is one of the promising areas to which robotic technologies can be applied.

A possible task of service robots is to move safely for guiding people or carrying items in public space such as a shopping center and a cafeteria. Realizing a safe movement of a robot is, however, a difficult mission especially when the robot moves among many people. Such a difficulty comes from, for example, a low reliability of environmental sensing. Since the motion planning function of the robot heavily relies on the quality of the environment recognition, it is still difficult to test the robot system in real environments.

We, therefore, develop a people movement simulator that models and simulates person's movement in public space. Using the simulator, we can easily and safely test our planning algorithms in various simulated environments.

Crowd simulation is an approach to analyzing collective behaviors of multi-agent systems. Raynolds [1] proposed a model of coordinated animal motion such as bird flocks, which has three relatively simple rules for coordination: separation, alignment, and cohesion. He used this model to create computer animation of flock of birds (*birds*). Hebling et al. [2] developed pedestrian models for normal situations and for evacuation in panic situations based on a generalized force model of pedestrian dynamics.

Akuzawa and Taguchi [3] developed a simulator of people movement in the concourse of a station. They decompose people's movement to global and local movements and simulated the movements by combining a potential method and a spatial network-based path

planning. We take a similar hierarchical approach but use a different route search method and more elaborated expressions for representing people's local movement.

Most of previous works on people movement simulation is for simulating flow of people in public space. For this purpose, they model people's movement towards their destinations. In addition to modeling of such goal-directed movement, model the behaviors specific to the public space, such as queuing and the search of free seats.

The simulator has been implemented as an *RT component*, which is a software module running on *RT-middleware* environment [4]¹. Since our motion planning module has also been realized as an RT component, the motion planning module can easily be connected with the simulator for development, and then used for controlling a real robot without any modifications.

The rest of this paper is organized as follows. Sec. 2 describes a model of local movement based on a potential method. Sec. 3 describes a model of global movement based on a spatial network. Sec. 4 describes simulation results and the application to path planner development. Sec. 5 concludes the paper and discusses future work.

2. Modeling of local movement

Local movement is an action of moving to a goal position while avoiding surrounding persons and obstacles. The person's local movement is modeled by a potential method. A person is defined as a circle. A wall is defined as a segment that connects two points. Person's view is limited by a sector of 7.5m in radius and 120° in central angle (Left of Figure 1).

Each person recognizes people and objects that come within the field of view as long as they are not occluded by other people and objects. When a wall exists which intersects with the line connecting two persons, we judge that they cannot see each other (Right of Figure 1).

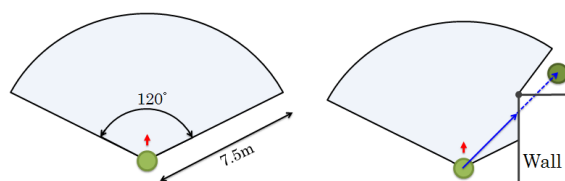


Fig. 1: Field of view

¹RT-middleware is a specification on a component model and infrastructure services applicable to the domain of robotics software development, authorized by OMG (Object Management Group).

2.1 Person's walking speed

People are not walking at a fixed velocity. The walking speed of a person changes depending on his/her surroundings. Each person slows down to avoid collisions in a crowd. We think that only people in the front and in a short distance influence the person. The influence region is defined as a sector of 2m in radius and 60° in central angle. We calculate the people density in the region and use it to control the person's speed.

Several research have discussed the relationship between the walking speed and the congestion (people density). The walking speed V of a person is determined by expression(1).

$$V = a - b \cdot K, \quad (1)$$

where a is the walking speed when influence from the surrounding is imposed and b is a constant that shows the relation between congestion K and walking speed. Values of a and b have been offered by existing researches, which are shown in table 1. It is desirable to use these values according to respective situations. We use, however, a simpler model given by

$$V = V_s - b \cdot K, \quad (2)$$

where V_s is the walking speed when no influence from the surrounding is imposed and does not change in any situations.

Table 1: Relation between walking speed and congestion [5]

Researcher	Situation	a	b
Yoshioka	Commuting	1.61	0.33
Yoshioka	Event	1.349	0.376
Yoshioka	Shopping	1.13	0.28
Mouri and Tukaguchi	Commuting	1.48	0.204
Takeuchi	In residential area	1.50	0.38
Fruin	Commuting	1.356	0.341
Older	Shopping	1.311	0.394
Oeding	Composite	1.50	0.394
Navin and Wheeler	In university	1.63	0.60

2.2 Determining person's moving direction by potential function

In this simulator, the moving direction of a determined person is decided by using a potential method as follows.

- A positive charge is given to persons, walls and other objects;
- A negative charge is given to the destination;
- The attractive and the repulsive forces between the charges are calculated;
- The moving direction determined as the composition of the attractive and repulsive forces.

Repulsive force F_{wall} from the wall is defined by

$$F_{wall} = -\frac{Q_{wall} \cdot e_{wall}}{|e_{wall}|^4}, \quad (3)$$

where e_{wall} is the vector to the nearest point on the wall in the environment and Q_{wall} is a constant (the amount of the charge) that determines the influence of the wall.

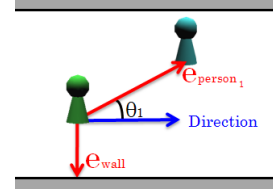


Fig. 2: Vector to wall and person

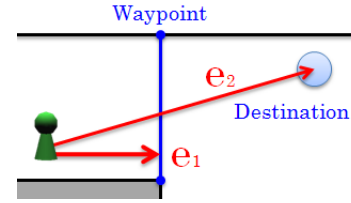


Fig. 3: Vector to destination

Repulsion from the other persons F_{person} is defined by

$$F_{person} = -Q_{person} \cdot \sum_{i=1}^{n_L} \frac{e_{person_i} \cdot \cos(\theta_i)}{|e_{person_i}|^2}, \quad (4)$$

where n_L is the number of people in the field of view, e_{person_i} is the vector to person i , Q_{person} is a constant that determines the influence of a person, and θ_i is the relative angle between the moving direction of a person, and person i . Figure 2 shows the vector to wall and person.

Similarly, F_{robot} from robots is given by

$$F_{robot} = -Q_{robot} \cdot \sum_{i=1}^{n_R} \frac{e_{robot_i}}{|e_{robot_i}|^2}, \quad (5)$$

where n_R is the number of robots in field of view.

Next, we think about the attractive force from the destination. The attractive force from a position is given by

$$F_i = \frac{e_i}{|e_i|} \quad (6)$$

The attractive force is normalized so that a certain amount of the force can be applied even for a distant destination (or waypoint).

People often cannot take a straight path toward the destination due to obstacles on the way. In such a case, he/she selects a path passing several waypoints². To simulate a smooth movement, we combine two attractive forces, one from the nearest waypoint and the other from the second nearest one, as shown in Fig. 3. A waypoint can be the destination when a person is near the destination.

In the figure, e_1 is the vector to the next waypoint and e_2 is the vector to the destination. If there is no waypoints, e_1 becomes the vector to the destination and e_2 is set to $\mathbf{0}$.

The attractive force from a position is obtained by the expression(6). In this expression, the attractive force from the destination and the waypoint is constant and not influenced by the distance, because the vectors are normalized. As a result, people can surely move to the destination even from a long distance.

²The definition of waypoints will be given in Sec. 3.1.

The combined attractive force $F_{forward}$ from the forces, F_1 and F_2 , from two waypoints is calculated by:

$$F_{forward} = \frac{F_1 + \frac{1}{2} \cdot F_2}{|F_1 + \frac{1}{2} \cdot F_2|} \quad (7)$$

This expression does not have any constant. because the relative importance factors of the other forces are defined relatively to this attractive force.

The direction of the resultant force F_{all} that is decided by surrounding people and robots, wall, and the destination and indicates the person's moving direction is given by

$$F_{all} = F_{forward} + F_{wall} + F_{person} + F_{robot} \quad (8)$$

2.3 Calculating a person's position at each time step

Position after the movement p_{next} is calculated from the current position p , the direction of F_{all} obtained by eq. (8), the moving distance given by velocity V (see eq. (2)), and time step Δt .

To avoid a large acceleration/deceleration of a person, we use an average of the velocity calculated from the current situation and the previous one as the current velocity, which is given by:

$$v = \frac{1}{2} \cdot \left(V \cdot \frac{F_{all}}{|F_{all}|} + v_p \right) \quad (9)$$

The position after the current movement is given by

$$p_{next} = p + \Delta t \cdot v \quad (10)$$

3. Modeling of global movement

People movement simulation in a simple environment such as a straight corridor can be done only by the local movement method. However, the movement of people in a complex environment where multiple pathways exist cannot be simulated only by the local movement. This section explains a route search method which is necessary in such cases. A cafeteria is supposed to be an example of public space in this paper. People's destination selection behaviors specific to the environment are also described.

3.1 Building a spatial network

To calculate a person's route, we divide the free space into subareas and a spatial network with the subareas being nodes is constructed. We can calculate the route from a subarea to another by using this spatial network. A subarea is defined as a rectangle that does not contain any walls in its inside. Borderlines of a subarea are either walls or adjacent subareas. A person calculates the route from the current subarea to the subarea of destination, and moves to the destination by tracing the subareas on the route. Waypoints are set as borderlines between subareas. When a person moves to a waypoint, the nearest position on the waypoint from the current person position is selected as the position to approach.

3.2 Route finding considering congestion

A route is calculated by using the A* algorithm. We use the distance and congestion (the people density) for determining the cost between nodes. As a result, we do not select the shortest route but a minimum time route.

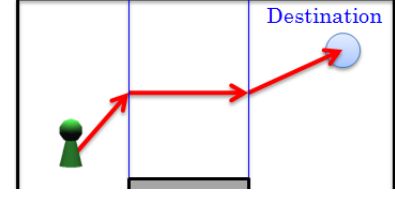


Fig. 4: Distance for route cost calculation

Speed V_a of people in a subarea is calculated by using eq. (1). The density in the subarea is used for density K . The time required spent in the subarea is calculated by

$$Cost_a = \frac{d_a}{V_a}, \quad (11)$$

where d_a is the travel distance inside the subarea.

The distance between subareas is given by (see Fig. 4):

- **Current subarea:**

Distance from the current position to the center of border to the next subarea;

- **Subarea on the way:**

Distance between the centers of the borders;

- **Subarea in destination:**

Distance from the center of border with the previous subarea to the destination.

The total cost is the summation of the times required for passing the subareas on the route, which is given by:

$$Cost = \sum_{a=1}^{n_A} Cost_a, \quad (12)$$

where, n_A indicates the number of subareas on the route. The minimum time route is selected as the best route.

3.3 Classification of destinations and people movement modeling at each destination

This paper deals with people's destination-directed movements. People behave differently depending on the destination to move. In this simulator, the destination is classified into the following four categories: "Exit", "Seat", "Queue", and "Point".

Exit This is a destination for going outside the simulation environment. It is defined as a segment, and a person moves toward the nearest point on the segment. The person who reaches the exit disappears from the simulation environment.

Seat This is a place occupied by a person like a bench in a passage. For instance, it is a bench on the passage or a chair in a cafeteria. People cannot select a seat as a destination when someone already exists there.

Queue This is a place where people form a queue like a line to a ticket vending machine or a ticket gate. This is defined by the position of the head of the queue and the direction of queuing. A person who wants to enter the queue moves towards its tail.

Point This is a place that a person chooses as a destination but is not classified as the other categories. This is defined by a circle (position of the center and the radius), and a person is judged to reach the destination when he/she enters the circle.

3.4 Selection of a destination

People sometimes select one destination from multiple ones of a kind, such as the case where he/she selects one of multiple exits or one of multiple ticket vending machines. To simulate such a behavior, we calculate the evaluation value of each destination and make a person select the best one. Evaluation function $E(d)$ is defined for each destination d .

The evaluation function for an exit is defined as:

$$E_{Exit}(d) = Cost(d) \cdot N(1.0, 0.2^2), \quad (13)$$

where $Cost(d)$ is the route cost to move to the destination d , that is the time necessary for the movement, and calculated by eq. (12). A normal distribution is multiplied to the cost to introduce some randomness to the behavior.

The evaluation function for a point is defined as:

$$E_{Point}(d) = Cost(d) \cdot N(1.0, 0.2^2) \quad (14)$$

This is the same as the expression for exits.

The evaluation function for a seat is defined as:

$$E_{Seat}(d) = (Cost(d) \cdot (1.0 + \rho)) \cdot N(1.0, 0.2^2), \quad (15)$$

where ρ is the density of the persons around the seat, which is given by the density of the subarea including the seat. We multiply $1.0 + \rho$ to the cost to simulate the people's behavior to avoid crowded areas. This eventually avoids the situation where all people select the nearest seats.

The evaluation function of a queue is defined as:

$$E_{Queue}(d) = (Cost(d) + N_q \cdot t_q) \cdot N(1.0, 0.2^2), \quad (16)$$

where N_q is the number of people in the queue and t_q is the time to receive service at the head of the queue per person. This expression estimates the time until the person comes off the queue, calculated as the sum of the time for reach the queue, that for queuing, and that for receiving service. Each person selects the queue for which the service will be finished earliest.

For all of the above evaluations, smaller values are better.

3.5 People's action sequence

People's behavior does not consist of a single action but of a sequence of actions; in the case of movement simulation, each person executes a sequence of movements from the entrance to the simulated environment to the exit from it. For example, a person may take the following sequence: queues up to the vending machine to buy a meal ticket, receives a dish at the counter for the ticket, moves to a free seat, and starts eating. The action of not moving such as eating is also be modeled and described for simulation. Each person is given a sequence of actions and he/she executes one action to another until all actions are executed.

4. Simulation experiments

We developed a simulator based on the above mentioned people movement models, and performed simulation experiments.

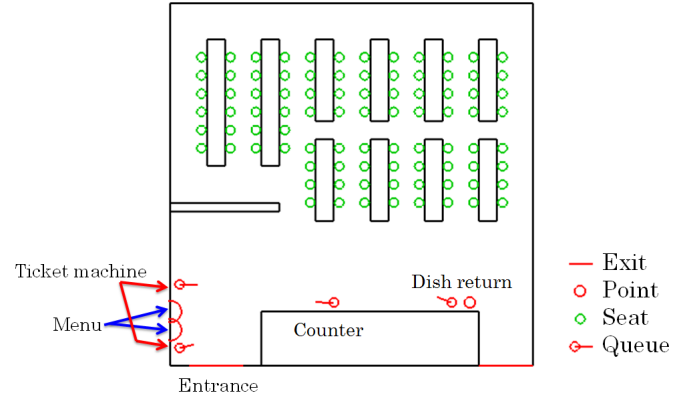


Fig. 5: Modeled environment

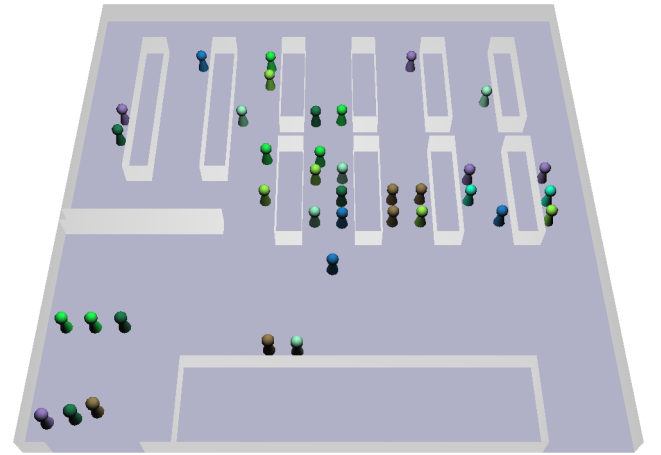


Fig. 6: Simulation

4.1 Simulator setup

We have developed a simulator which models the people movement in the cafeteria in our university. Figure 5 shows the modeled environment.

Figure 6 shows a simulated scene. We use OpenGL for graphics simulation. In this figure, cones with balls on their tops show people. We can simulate a people's behavior that checks the menu, queues to a ticket vending machine, receives a dish with the counter, eats in the seat, returns tableware, and goes out from the exit.

Figure 7 shows a simulated scene that is queuing and figure 8 shows a scene that is a person goes through between persons.

When the number of people in the environment is about 30, the execution time of one cycle of simulation is below one millisecond. Since lots of people are halting for sitting or queuing in our environment (i.e., cafeteria) and motion planning is not necessary for them, we can simulate more people simultaneously in real-time.

4.2 Application to path planner development

Testing a path planner in various environments is important for fast and reliable planner development. It is, however, difficult to test the planner in an actual environment because environment recognition is sometimes hard to be reliable. We thus connect the path planner with the simulator for the test in various situations.



Fig. 7: Simulation scenes (Queuing)

We have been developing a randomized path planner for a mobile robot and implemented it as an RT-component [6]. By also implementing the simulator as an RT-component, we can connect these components directly as shown in Fig. 9 [7]. Using this configuration, the path planner, tested and refined in the simulated environment, can directly be applied to an actual robot.

Figure 10 shows snapshots of the person following behavior of the robot. In the left column, the red cube with a ball on the top indicates the robot. The robot is instructed to follow the red person. The right columns shows the results of environment recognition and path planning. In this figure, yellow lines indicates the randomized path search, the red line indicates the selected path, green circles indicate stopping people, and triangles indicate moving people.

Using this environment, we can see if the path planning algorithm works well in a respective situation.



Fig. 8: Simulation scenes (Go through between persons)

5. Conclusion

This paper has described a simulator for people movement in public space and its application to robot path planner development. The simulator models not only a simple goal-directed movement of people but also behaviors in specific scenes in a cafeteria. The experimental results show the people's behavior in cafeteria is well simulated. The simulator has been applied to path planner development by implementing both the simulator and the path planner as RT components.

Several directions are possible as future work. One is to apply the simulator to the development of a more advanced path planning algorithms, such as the one which considers people's flow and/or behavior in specific situations. Another future work is to improve the simulation model so that it can simulate people's more natural behaviors such as smooth passing by in a narrow space and movement that avoidance of queues.

Acknowledgment

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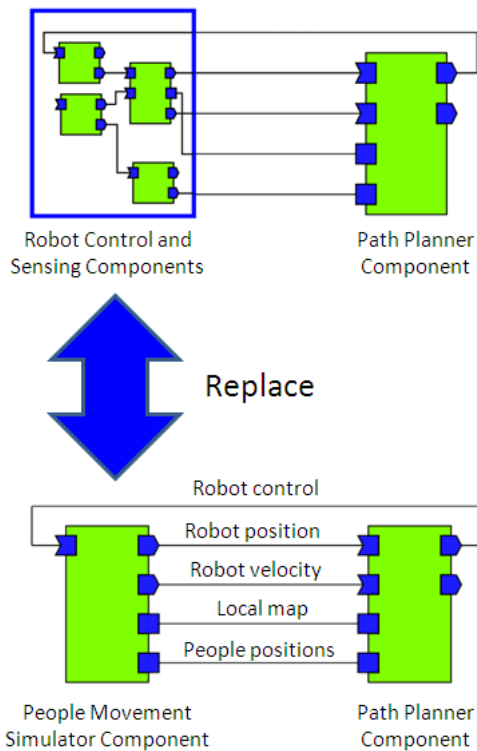


Fig. 9: Path planner development environment constructed by RT components

REFERENCES

- [1] C.W. Reynolds, "Flocks, Herds, and Schools: A Distributed Behavioral Model", *Computer Graphics*, Vol. 21, No. 4, pp. 25–34, 1987.
- [2] D. Helbing, I.J. Harkas, P. Molnar, T. Vicsek, "Simulation of Pedestrian Crowds, in Normal and Evacuation Situations", *Proc. of Pedestrian and Evacuation Dynamics 2000*, pp. 21–58, 2000.
- [3] Azumi Akuzawa, Azuma Taguchi, "A Study of Simulation Model for Pedestrian Movement in a Station Yard", *Abstracts of 2005 Autumn Forum of the Operations Research Society of Japan*, pp. 192–193, 2005 (in Japanese).
- [4] Ando, N., Suehiro, T., Kitagaki, K., Kotoku, T., Yoon, W.K.: RT-middleware: Distributed component middleware for RT (robot technology). In: *Proceedings of 2005 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp. 3555–3560, 2005.
- [5] Kimitaka Okada, Takeshi Wada, Yukio Takahashi, "Walking model and people flow simulation based on person's behavior", *Abstracts of 2003 Spring Forum of the Operations Research Society of Japan*, pp.102-103, 2003 (in Japanese).
- [6] Yuki Ishikawa, Kenta Kitajima, Junji Satake, Jun Miura, "Development of Path Planning RTC for Dynamic Environments", *The 27th Annual Conference of The Robotics Society of Japan*, 2009 (in Japanese).
- [7] Yuki Ishikawa, Atsushi Shigemura, Junji Satake, Jun Miura, "Development of a Mobile Robot Path Planning Algorithm and Its Verification using a Multi-Person Movement Simulator", *Proceedings of the 59th Annual Conference of Tokai Branch, the Japan Society of Mechanical Engineers*, 2010 (in Japanese).

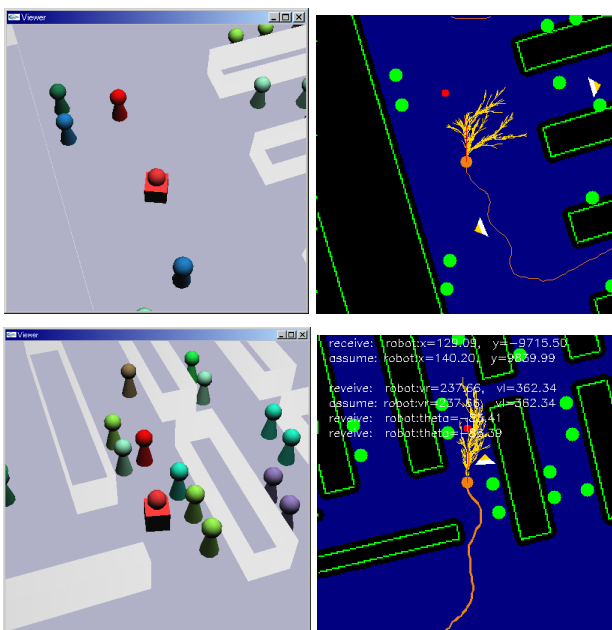


Fig. 10: Simulation with path planning algorithm