A Method for Modeling of Pedestrian Flow in the Space with Obstacles using Laser Range Scanners

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Abstract - The measurement of the pedestrians' movement has high utility, because many efficient services can be provided for pedestrians with the measurement data. There are some techniques to measure pedestrian traffic and especially the method to measure pedestrian traffic with laser range scanners attracts considerable attention recently. However, the lines of sights of the laser range scanners are obscured by obstacles. Therefore, it is difficult to completely capture all the pedestrians' movement in the target area. In this paper, we propose a method that estimates pedestrian traffic from sectional population density instead of individual pedestrians' data. Our method also generates pedestrians flow. We have evaluated the proposed method with ideal scenario data. The experimental results have shown that our method could reproduce pedestrian traffic with about 80% accuracy.

Keywords: Laser Range Scanner, Estimation of Trajectory, Pedestrian Flow

1 INTRODUCTION

With the recent development of the sensing technology, various phenomena can measured in the real world and the services using these measurement data become able to be provided. As such an example, Cyber Physical System attracts attention. The construction of the smart society by various services using various sensors becomes one of the new issues in the future information and communication technology. Among phenomena to be targeted for the measurement of the sensor, a tendency of the movement of the pedestrians (pedestrian flow) attracts attention recently. The information of pedestrian flow becomes important because this information in roads or the underground shopping center is available for the orientation of various services and the control of pedestrian flow.

For the mainstream method of the pedestrian flow measurement, there is the method that processes the images recorded by cameras, and tracks the pedestrian using the information. However, in the method using the camera, there are the privacy problem of target pedestrians and the problem of setting cost and the angle of view of cameras. In contrast, the measurement of the pedestrian flow with the laser range scanner attracts attention from a demand to measure the rough tendency of the pedestrian flow at low cost. The laser range scanner can scan a wide area fast. There is little fear to infringe the privacy information of pedestrian targeted for a measurement, because the measurement data which laser range scanner acquires are only positional information expressed as direction and distance for the scanner. In addition, the calculation cost is relatively small because the size of scanner data is much smaller than images. However, the laser range scanner is easy to lose sight of measurement objects by occlusion, and it is difficult to completely measure the all behaviors of all pedestrians in the measurement area.

In this paper, we propose the method for modeling pedestrian flow by estimation of the routes that the pedestrians would have passed not from the individual positional data of each pedestrian but from the population density at each division of the measurement area. In our method, the measurement area is divided in the division of constant size at first. Next, in each division, the number of pedestrians is counted using laser range scanner, and the population density in the division is calculated. Finally the course where pedestrian passed is estimated from the population density and generate pedestrian flow model. In this way, our method can generate the pedestrian flow model from the data that the all behaviors of all pedestrians are not observed.

2 RELATED WORK

2.1 Methods of measuring pedestrian flow

There are various methods to track the pedestrians. For example, a tracking method using images recorded by video cameras is often used. There is a method to measure pedestrian flow by recognizing the head of the pedestrians and tracking automatically using a stereovision camera. However, the measurement using cameras has much quantity of data, and the calculation cost becomes high. And from the viewpoint of privacy, the setting of the camera may be restricted.

There is another method to let each pedestrian hold the RFID tag which sends unique ID. This method estimates the position of each pedestrian from the position of the ID receiver and ID sent from RFID tags, and tracks pedestrians. However, for the tracking using the RFID tag, it is necessary to build the environment where ID receivers are deployed enough and to let pedestrians hold the terminal with RFID tag.

There is a method to estimate overall pedestrian flows from the flow quantity of each gateway by counting the passage number of people. However, if the instrumentations are affected by the occlusions, there is a problem that the numbers of the pedestrians who are not measured definitely increase as quantity of traffic increases. In addition, because only the number of passing pedestrians is measured, some behaviors such as stopping in the measurement area cannot be detected.

Some method using laser range scanners are proposed. Reference [1] measures the ankle of the pedestrian using scanners, detects walking rhythm of the bipedalism from the movement pattern of the ankle and tracks the pedestrian. However, in actual environment, this method may be influenced by the existence of the bag with the caster. Therefore it is necessary to devise measurement procedure.

2.2 Method of generating pedestrian flow model

The generation of pedestrian flow model is mainly used in the simulation of mobile wireless networks. Simple models such as Random Way Point Model [2] are often used for pseudo node mobility models. In late years some researches [3]–[6] to propose the mobility equal to subspecies of Random Way Point Model are performed. Many mobility models to compose realistic mobility by the measurement data and the geographical information have been proposed. Ref. [7] proposes the model to reproduce the interception of the radio wave by the buildings(obstacles), and the mobility model that nodes avoid those buildings. The method of Ref. [8] divides the simulation domain into some zones depending on the characteristic such as a residential area or a business district. And the method estimates the change of the density of every node classification by zonal unit using existing traffic planning method.

In Reference [9], Weighted Way Point Model is proposed. This method defines the domains with many people such as a cafe or the university, and models the movement of nodes between domains using Markov model by giving distribution of the sojourn time in each domain and the transition probability between domains. Time Slot Urban Pedestrian Flows model [11] estimates realistic movement routes on given road structure and derives the traffic quantity of each route to satisfy given density.

3 PEDESTRIAN FLOW MEASUREMENT USING LASER RANGE SCANNERS

3.1 Characteristic of the laser range scanner

A laser range scanner is the sensor which can measure the distance from a sensor to an object using the spread time of laser beam. And this sensor has characteristic to scan wide area fast. But, there is the fault to lose sight of the pedestrian targeted for the measurement when the pedestrian is hidden by the shade of obstacles such as pillars or different pedestrians(the occlusion problem). The laser range scanners which we used for pedestrian flow measurement is UTM-30LX [12] made by HOKUYO AUTOMATIC CO., LTD. Table 1 shows the specifications of this sensor. As for this sensor, the tracking of a pedestrian targeted for the measurement is possible [17].

Table 1: UTM-30LX

Item	Spec
Detection Range	$0.1 - 30m, 270°$
Angular Resolution	$0.25°$
Scan Time	$25ms/scan$
Accuracy	$0.1 - 10m : \pm 30mm$
	$10 - 30m : \pm 50mm$
Size	$W60 \times D60 \times H87mm$
Weight	$370g$

3.2 Precedent experiment

A precedent measurement experiment was conducted in underground shopping center "Whity Umeda" of the neighborhood of subway Umeda Station of Osaka. We measured the pedestrians by synchronizing four UTM-30LXs. Figure 1 shows the measurement area and the installing position of the laser range scanners. The installed laser range scanners are expressed as the orange column of Fig. 1, the movable range of pedestrian is expressed with beige. The data measured by

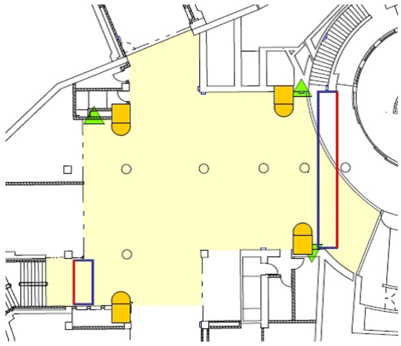

Figure 1: Installation position of laser range scanners

UTM-30LX are position coordinate data of the pedestrian in the measurement area every one second, and the unit of coordinate supports mm of the real world. In addition, specific ID is assigned to the pedestrian who appeared newly in the measurement area. While the tracking with the sensor succeeds, the identification of the same person is possible by this ID because the ID is unchangeable.

The data measured by UTM-30LX are following three.

- Measurement time: t
- Position coordinates of the pedestrian: (x, y)
- ID of each pedestrian assigned to by the tracking of the laser range scanners: i

After analyzing actual measurement data, the tracking in UTM-30LX is proved that it could continue only for a short time by the occlusion problem. The life time of the ID from 30% to 40% was approximately one second. It is caused by the following that a success period of the tracking shortens.

- A pedestrian is hidden behind obstacles such as pillars
- A pedestrian is hidden behind other pedestrians
- There are some pedestrian staying by the wall where sensors are installed and they narrow the measurement range of the sensor.

There are some methods to solve these problems. For example, they are methods to increase the number of sensors and method to use sensors which are not affected by obstacles. However, these methods have high cost.

4 PROPOSED METHOD

4.1 Overview

Because of the characteristic of laser range scanner, it is difficult to completely measure the behavior of all pedestrians when laser range scanners are used for measuring pedestrian flow. On the other hand, changes of pedestrian flow as the whole is regarded more important than each personal behavior in the scene where the pedestrian flow is used including trajectory analysis of customer in commercial facilities and pedestrian flow analysis for refuge instructions. In this paper, we pay attention to the change of the population density in the partial domain in the measurement area. Generally, the population density on the route that many people pass becomes higher, and population density changes along the direction of the pedestrian flow. Using this characteristic, our method extracts the characteristic of the pedestrian flow in the measurement area.

In our method, at first the measurement area is divided in the plural square domains of the equal size (unit cells), and the population density of each cell is calculated by the positional data of the pedestrian. From a tendency of the population density of each cell, our method estimates the cell which the pedestrians passed and estimates the routes of the pedestrians. The direction ratio of pedestrian via the estimated route is decided based on the directional information of pedestrian provided by the tracking with the laser range scanners. Our method expresses the number of pedestrians via certain route and the movement direction of the route in the form of the flow. This flow is the proposed pedestrian flow model.

4.2 Generation method of pedestrian flow model based on the population density

In this method, we use the measurement data and the tracking data of the laser range scanners for the measurement of the pedestrian. The tracking of the walker with the range scanner succeeds only for several seconds, 30% - 40% of IDs are measured only for about one second. Some pedestrians are expected to continue moving without being measured by sensors for a long period. Therefore to estimate the movement of the pedestrian we use the population density of the cells for certain constant period. The following assumptions are put for the movement of the pedestrian.

- Assumption 1 Pedestrians moves to the adjacent cell of top and bottom right and left from the cell which oneself is now.
- Assumption 2 Pedestrians move from the entrance to the exit without making a detour under Assumption 1.
- Assumption 3 Pedestrians are measured once in each cell which he/she passes.

The pedestrian flow model is generated in the following procedures.

1. Division to the unit cells of the measurement area
2. Choice of the gateway cells
3. Supposition of the route candidate between the gateways
4. Calculation of the population density of each cell
5. Calculation of the number of sojourners
6. Estimation of the route where the pedestrian passed and its traffic
7. Determination of direction of the flow

The details of each processing are as follows.

1. Division to the unit cells The measurement area is divided into cells like Fig. 2. Any size can set as the size of the cell. But it becomes hard to get the tendency of the movement of the pedestrian group as much as the size becomes large. And it costs for the calculation of the movement route of the pedestrian as much as the size becomes small. We assume the size of the cell 6.3m every direction in consideration of the speed of the pedestrian and the size of gateways.

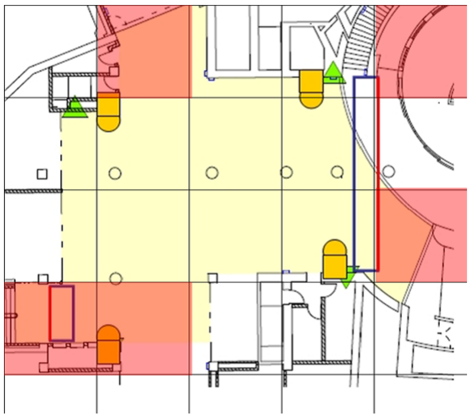

Figure 2: Target area divided into unit cell

2. Choice of the gateway cells We assume the cells in the border of the domain where sensors can measure and the domain where sensors cannot measure a gateway cells. The reddish cells are gateway cells in Fig. 2.

3. Supposition of the route candidate between the gateways For two different gateway cells, we assume a route between them as a route candidate. According to Assumption 1 and 2, we enumerate the route candidates for the combination of all gateway cells. Figure 3 shows the state to assume route candidates from two gateway cells. Yellowish green lines are the route candidates.

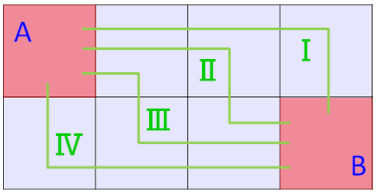

Figure 3: Assumption of route candidate

4. Calculation of the population density of each cell Using the measurement data of the laser range scanner for the constant period of time, the population density of the cells is calculated. Our method count it up how many pedestrians existed in each cell from the positional coordinate data of measured pedestrians during the measurement period (Fig. 4). Because the sizes of all cells are the same, the counted number of people is considered as the population density of the cells.

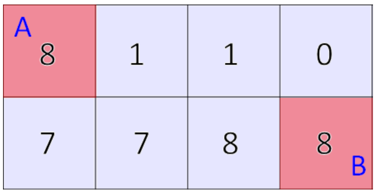

Figure 4: Calculation of density of cells

5. Calculation of the number of sojourners In the measurement area, some people may exist without moving (sojourners). By this method, the sojourners may be counted several times, and the population density of the cell where the sojourners are may grow large unnaturally, because sojourners are hidden behind other pedestrians. Therefore, it is necessary to exclude the data of sojourners not to influence the value of the population density. We set the minimum movement speed v_{min} for the pedestrian data succeeding for tracking, and exclude the measurement data of a pedestrian moving at a speed less than v_{min} at the time of the population density calculation.

It is necessary to know the number of sojourners because the control of sojourners is needed for the control of the pedestrian flow. Therefore our method calculate the mean number of sojourners during a measurement period based on the number of the pedestrians moving at a speed less than v_{min} which are excluded at the time of the population density calculation.

6. Estimation of the route where the pedestrian passed and its traffic The route that the pedestrian passed is estimated from route candidates and the population density of each cell. Pedestrian is less likely to pass the cell with the small population density and pedestrian is more likely to pass the cell with the large population density. From assumption 3, when one pedestrian passed a certain route, the population of the cell which the route passes increases 1. As a result, the population density also increases 1. Based on this assumption, our method calculate the route and the traffic, so that the population density of each cell calculated from the decided quantity of flow and the decided route becomes near to the population density of each cell really measured. Because there is much number of route candidates, and the calculation cost of verifying all combinations, we use the greedy algorithm for calculating the optimum route. The optimum route here is the route where the possibility that pedestrians pass is the highest when the population density of each cell was given. The criteria of the optimum route are as follows.

- Do not pass a cell with population density less than 0 as much as possible.
- Pass the cell which is high in population density with precedence.

The optimum route is calculated as follows by the greedy algorithm. At first, the most suitable route candidate for given population density is chosen as the temporary optimum route. The population density of each cell except the pedestrians via the temporary optimum route is calculated again. The optimum route is calculated by repeating the same process for the population density that updated a value. When one route corresponds to one pedestrian, the processing to remove pedestrians via the route corresponds to the process of reducing the population density of the cell which a route decided from Assumption 3 passes. When all the routes are decided and the population density of all cells became 0, the combination of I might calculate for the original population density might be calculated. Therefore the calculation by the greedy algorithm is repeated and finished when the total absolute value of the population density of all cells is minimized. The routes decided by the end of the processing expresses the course where each pedestrian passed. The number of each decided route expresses the number of pedestrians via the route. The route calculation processing is explained below by a specific example.

1. Calculate the most suitable course candidate as input by population density
   For example, the population density such as Fig. 4 is assumed input. The number of figures expresses the population density of the cell. The route candidates in this domain are I - IV of Fig. 3, and with the case of Fig. 4, route IV becomes the most suitable route candidate.

2. Check the total absolute value of the population density of all cells whether the most suitable route candidate may be chosen as a route
   The current total absolute value of the population density is 40, and the total value when the route candidate IV is chosen as a route is 35. Because the total absolute value of the population density becomes small, this route candidate is chosen as a route.

3. Output the value that updated the population density of the cell which the route passes
   Because one route corresponds to one pedestrian, the

population density of the cell which the chosen route passes is decreased 1. Route candidate IV is chosen in Fig. 3 as a route and Fig. 5 shows the value of the each cell is updated.

4. Return to (1) by the output in (3) as new input
The whole processing mentioned above is repeated by population density of Fig. 3 as new input.

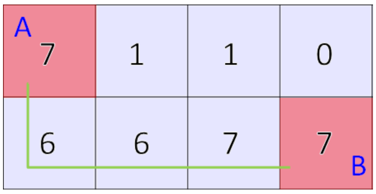

Figure 5: Population density when route IV is chosen

7. Determination of direction of the flow The information about quantity of flow and direction are necessary for pedestrian flow model. Therefore the direction of the pedestrian's movement via the route estimated from population density is needed. Because it is difficult to estimate the movement route of the pedestrian only from the positional coordinate data (x, y), we use the tracking function of the laser range scanners. The direction of the pedestrian's movement can be estimated from the position difference of an equivalence person provided by tracking while tracking succeeds. If a certain route p between gateway cells $g1$ and $g2$ are given, the direction of the pedestrian's movement in each cell which the route passes is examined. About a pedestrian moving along the route, the number of people according to a movement direction (someone move towards $g2$ from $g1$ and someone move towards $g1$ from $g2$) is counted. From the result of counting, the direction ratio of the pedestrian's movement is calculated, and the quantity of flow of the route is divided to accord with this ratio. In this way, the quantity of flow from $g1$ to $g2$ and the quantity of flow from $g2$ to $g1$ on the route p are obtained.

Figure 6 shows a specific example. The points in a figure express a pedestrian, and the arrows connected to each point express the direction of the pedestrian's movement. The long arrows between gateway cell A and gateway cell B expresses routes between A and B. The quantity of flow of the route is expressed by the number of the arrow. In the example of Fig. 6, the quantity of flow of the route between A and B is 3, and there are 3 walkers in each cell which the route passes. When the number of pedestrians is counted according to the direction of movement, the number of pedestrians toward cell B from cell A (the pedestrian with red arrow) is 10 and the number of pedestrians toward cell A from cell B (the pedestrian with blue arrow) is 5, because each pedestrian moves along the route. As for the direction ratio, the pedestrian toward B from A becomes 66.7% and the pedestrian toward A from B becomes 33.3%. Our method divide quantity of flow according to this ratio, and obtain a flow with 1 quantity toward A from B (blue arrow) and flows with 2 quantity toward B from A (red arrows).

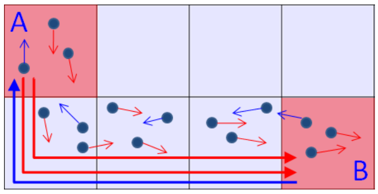

Figure 6: Determination of direction of the pedestrians' movement

The pedestrian flow model is generated in the flow form from the direction and quantity information of the flow by the above-mentioned processing.

From the measurement data which the experiment in "Whity Umeda" provided, the pedestrian flow models are as follows by the proposed method. The pedestrian flow model is generated from 10-minute measurement data until 8:26:08 a.m. on December 24, 2010 from 8:16:09 a.m. on December 24, 2010. The measurement area is a rectangular domain of $31.4m \times 27.7m$, and the size of the cell is $6.3m$ square. This area is divided in unit cells. The number of pedestrians who existed in each unit cell for 10 minutes is counted and this number is considered as the population density of pedestrians in each unit cell. To calculate an average flow per time, the quantity of the pedestrian flow is calculated from the population density that averaged the data for 10 minutes in the area for 1 minute. Figure 7 shows the population density of each cell obtained from measurement data.

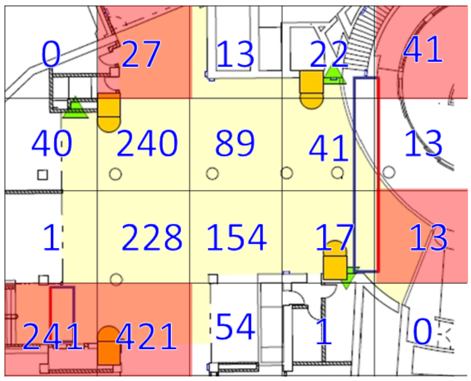

Figure 7: Population density (8:16:9 - 8:26:8)

Figures 8 and 9 show the pedestrian flow model generated from population density of Fig. 7. Figure 8 is a figure expressing each pedestrian flow from a certain gateway cell to a different gateway cell. Figure 9 expresses pedestrian flow of throughout the measurement area by expressing quantity of movement to the cell which is adjacent for each cell as arrows. The direction of the arrow is the direction of the pedestrian flow, and the quantity of the pedestrian flow is proportional to the thickness of the arrow. The numbers in figures expresses the number of the sojourners of the same cell for 1 minute. The movement speed v_{min} which is standard to judge a sojourner or a pedestrian is assumed $20cm/s$.

Furthermore, another pedestrian flow model is generated from the measurement data until 6:36:08 p.m. on December

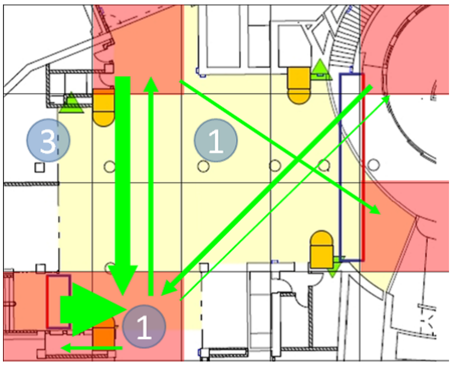

Figure 8: Pedestrian flow (Gateway to Gateway)

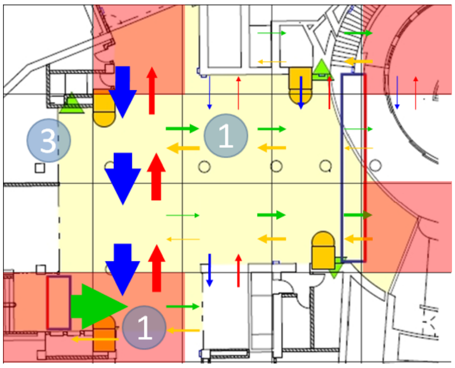

Figure 9: Pedestrian flow (Cell to Cell)

24, 2010 from 6:26:09 p.m. on December 24, 2010 on the equal conditions. Figure 10 and Fig. 11 show the generated pedestrian flow model.

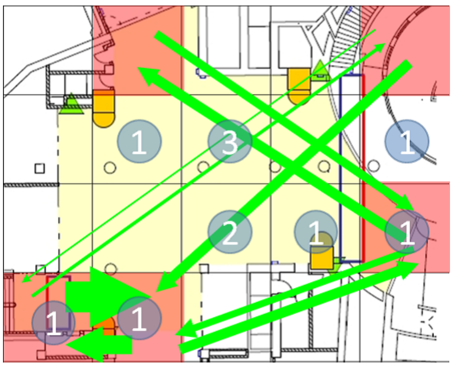

Figure 10: Pedestrian flow (Gateway to Gateway)

Because there are many people moving for commuting and attending school in the time of the morning, the characteristic flow that there is much movement quantity for the same direction is seen. People toward various directions are detected in the evening time. In addition, the existence of the sojourner is outstanding because there are many people to stop in open spaces such as the measurement area.

We also reproduced the people moved along flows based on the flow on Fig. 9 and Fig. 11, using MobiREAL Animator [13] realistically to output comprehensible animation data

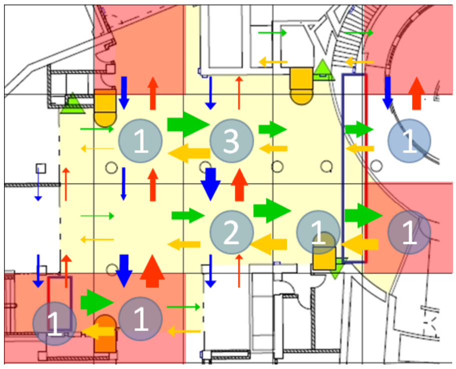

Figure 11: Pedestrian flow (Cell to Cell)

visually.

5 PERFORMANCE EVALUATION

Because of the failure in the tracking of the pedestrian by occlusion, the measured data which completely caught all pedestrians in the measurement area cannot be acquired using laser range scanners. Therefore, we artificially generate the scenario data which the behavior of all pedestrians can completely reproduced based on actual survey data by counting the number of people. And the pedestrian flow model is generated using the proposed method for this scenario data. By comparing this produced pedestrian flow model with the scenario data, we evaluate the reproducibility of the proposed pedestrian flow model to the scenario data. We compared the flow quantity toward exit cell g_2 from entrance cell g_1, and examined how much quantity of flow is reproduced.

The scenario data is generated from the data measured in ”Whity Umeda”. The position of gateway cells and the size of each cell make setting same as Fig. 2. Figure 12 expresses flows of the movement of pedestrian of the scenario data which made from the measured data of about 8:00 a.m. of December 24, 2010. The reddish cells in the figure are gateway cell (A - E), and the black arrow expresses the movement of pedestrians of scenario data. The thickness of the arrow expresses to the flow quantity of pedestrians. There are particularly many pedestrians moving between A - D or C - D in this scenario. We evaluate the precision of the proposed model for the state with many pedestrians who move to top and bottom, right and left for a cell by the index of the reproduction rate. The reproduction rate means the ratio that the flow generated by proposed method reproduces the flow of each route in scenario data. Figure 13 shows the comparison between scenario data of Fig. 12 and the flow quantity of routes linking each gateway cell of the generated pedestrian flow model. Though some false detection occurs, the average reproduction rate of the pedestrian flow quantity is about 82.9%, and pedestrian flow can be reproduced almost definitely by the proposed method.

Next, we evaluate the model using the scenario data which made from the measured data of about 6:00 p.m. of December 24, 2010. Figure 14 expresses flows of the movement of pedestrian of the scenario data. There are particularly many pedestrians moving between A - E or B - D in this scenario.

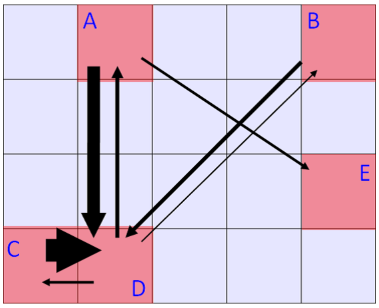

Figure 12: Scenario modeling from measured data in the morning

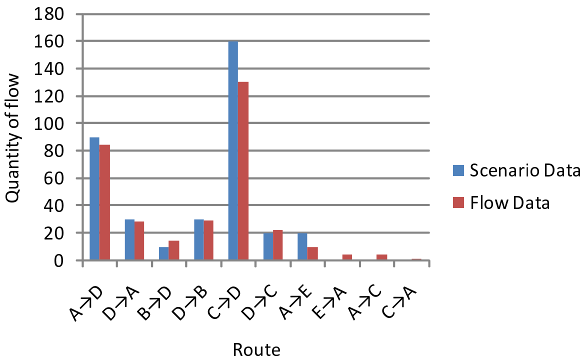

Figure 13: Comparing scenario data and generated flow

We evaluate the precision of the proposed model for the state with many pedestrians who move for a cell diagonally. Figure 15 shows the comparison between scenario data of Fig. 14 and the flow quantity of routes linking each gateway cell of the generated pedestrian flow model. The average reproduction rate of the pedestrian flow quantity is about 82.9%, and pedestrian flow can be also reproduced almost definitely in this case.

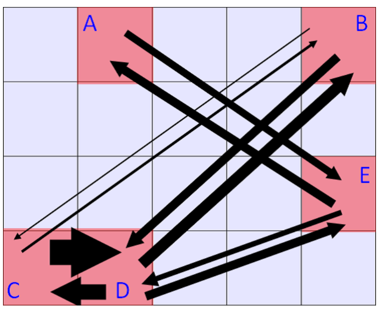

Figure 14: Scenario modeling from measured data in the evening

Finally, we evaluate the model using the scenario data which made from the measured data of about 1:00 p.m. of December 24, 2010. Figure 16 expresses flows of the movement of pedestrian of the scenario data. Pedestrians move to various courses in this scenario. We evaluate the precision of the

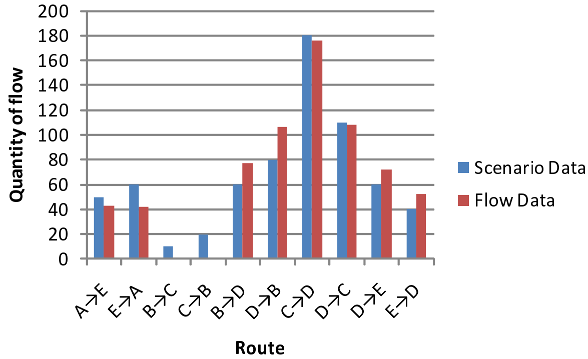

Figure 15: Comparing scenario data and generated flow

proposed model for the state that there are the moving pedestrians to various courses at the same time. Figure 17 shows the comparison between scenario data of Fig. 16 and the flow quantity of routes linking each gateway cell of the generated pedestrian flow model. The average reproduction rate of the pedestrian flow quantity is about 59.6%. In this case, pedestrian flow cannot be reproduced definitely. It depends on the difficulty of the distinction of a pedestrian moving between C - E, B - C and a pedestrian moving between D - E, B - D respectively, because gate way cell C and D are adjacent.

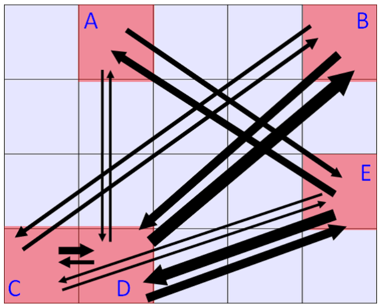

Figure 16: Scenario modeling from measured data in the afternoon

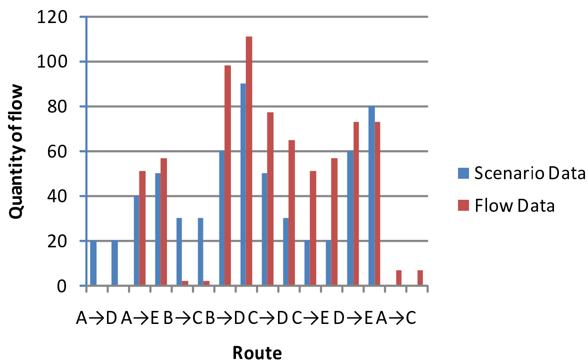

Figure 17: Comparing scenario data and generated flow

6 CONCLUSION

In this paper, we proposed the method for modeling of pedestrian flow in the space consisting of some gateways, some passages and various obstacles such as underground shopping center. The proposed method estimates the routes that the pedestrians would have passed not from the individual positional data of each pedestrian but from the population density at each cell of the measurement area. As a result, the proposed method can generate the pedestrian flow model from the data that the all behaviors of all pedestrians are not observed.

Future works include the model generation using the sojourner information of pedestrians, and the revision of the population density of each cell by the complement of the pedestrians who cannot observe by laser range scanner.

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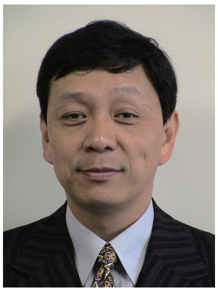

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