RESTORATION OF FRAGMENTARY TRAJECTORIES USING EVALUATION OF IDENTITY AND COMBINATORIAL OPTIMIZATION

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ABSTRACT: In this research, we propose the method which detects the optimum matching of the fragmentary trajectories using the method of evaluating identities of pedestrians and the method of combinatorial optimization. Our proposed method helps us understand the flows of pedestrians at certain space by restoring the fragmentary trajectories of the same pedestrians. In addition, we verify the accuracy of proposed method by applying it to the fragmentary trajectories tracked at the concourse of the railway station in Tokyo at the rush hour using laser range scanners.

1. INTRODUCTION

It is very applicable to various fields, such as security, spatial design, marketing etc, to track the movements of pedestrians and understand the flows of pedestrians at the space represented by the utilities, such as the stations and the airports, and the commercial facilities, such as the department stores. These spaces have characteristics in common that many pedestrians pass through every day and the flows of pedestrians are excessively complex. So there are a lot of existing researches about the methods of tracking movements of pedestrians. For example, (T.Zhao, 2004) proposed the method using CCD cameras, (T.Doki, 2006) proposed the method using plural cameras, (K.Nakamura, 2004) proposed the method using laser range scanners. Thus, a lot of methods are proposed and the accuracy of each method is verified by experiment.
But, even though we use the former methods, it is very difficult to completely track the movements of pedestrians from beginnings to ends because of the influences of the occlusions and the limitations of the number of cameras and laser range scanners which are possible to be set at certain space. Therefore, there are a lot of trajectories tracked only the fragmentary movements of pedestrians because of the failure of tracking and these trajectories make it difficult to understand the flows of pedestrians at certain space.
In this research, mainly targeting at the trajectories tracked using laser range scanners, we propose the method which detects the optimum matching of the fragmentary trajectories using the method of evaluating identities of pedestrians and the method of combinatorial optimization in graph theory. Our proposed method helps us understand the flows of pedestrians at certain space by restoring the fragmentary trajectories of the same pedestrians. In addition, we verify the accuracy of proposed method by applying it to the fragmentary trajectories tracked at the concourse of the railway station in Tokyo at the rush hour using laser range scanners.

2. RESTORATION OF FRAGMENTARY TRAJECTORIES

In this section, we explain about two methods applied to the fragmentary trajectories tracked using laser range scanners in order to restore them. One method is to evaluate identities between the fragmentary trajectories and the other method is to detect the optimum matching of the fragmentary trajectories.

2.1 Evaluation of Identity

First, we explain about the method of evaluating identities of the fragmentary trajectories. In this research, we define the evaluating index of identities as the cost to connect the $Traj\ i$ with connect $Traj\ j$. We simulate the behavior of $Traj\ i$ after $Traj\ i$ is disappeared using the particles which are scattered from the end point of $Traj\ i$ and move according to the spatial information stored in advance. So, the connection cost is defined as the distribution of probability density of the particles where and when the start point of $Traj\ j$ is appeared.

2.1.1 Storage of Spatial Information

In this section, we explain about the spatial information used for the movements of the particles. In this research, we divide the object space into several grids and define the spatial information as the distribution of the probability density of each direction in each grid, mean of velocity, variance of velocity and mean of the square of velocity displacement of pedestrians passing through each grid. These values are evaluated by N_v velocity vectors included in the trajectories tracked at the object space as the supervised data.

When the representative point of grid $G(p,q)$ is $P_G(x_{p,q}, y_{p,q})$, the start point of velocity vector V_i is $P_V(x_i, y_i)$, the direction of it is θ_i, we define the distribution of probability density toward $\theta_{p,q}$, $\Pr_G(x_{p,q}, y_{p,q}, \theta_{p,q})$, in $G(p,q)$ as follow equation according to kernel density estimation method.

$$\Pr_G(x_{p,q}, y_{p,q}, \theta_{p,q}) = \frac{1}{N_V}\sum_{i=1}^{N_V} \frac{\exp\left\{-\frac{1}{2}\left(\frac{(x_{p,q}-x_i)^2}{h_x{}^2} + \frac{(y_{p,q}-y_i)^2}{h_y{}^2} + \frac{(\theta_{p,q}-\theta_i)^2}{h_\theta{}^2}\right)\right\}}{(2\pi)^{3/2} h_x h_y h_\theta}$$

where h_x, h_y, h_θ are the standard deviations about x, y, angle.

In addition, mean of velocity $v_{mean}(p,q)$, variance of velocity $v_{\mathrm{var}}(p,q)$ and mean of the square of velocity displacement $v_{dp}(p,q)$ of pedestrians in $G(p,q)$ are evaluated by velocities and velocity displacements of the velocity vectors whose start points are included in $G(p,q)$.

2.1.2 Decision of Direction and Velocity of each Particle

Second, we explain about the method of deciding directions and velocities of scattered particles. The position of particle *m*, *t* frames after scattering from the end point of $Traj\ i$, is $P_{m,t,i}(x_{m,,t,i}, y_{m,t,i})$, the direction of it is $\theta_{m,t,i}$, the velocity of it is $v_{m,t,i}$, the grid that particle *m* exists is $G(p',q')$. Then, we define likelihood $l_{m,t}(\theta)$ that particle *m* will move in the direction of θ as the product of $\Pr_G(x_{p',q'}, y_{p',q'}, \theta)$, the distribution of probability density toward θ in $G(p',q')$, and the value of normal distribution whose mean is $\theta_{m,t,i}$, and define likelihood

$l'_{m,t}(v)$ that particle m will move at the velocity of v as the product of the value of normal distribution whose mean is $v_{mean}(p',q')$ and variance is $v_{\mathrm{var}}(p',q')$, and that of normal distribution whose mean is $v_{m,t,i}$ and variance is $v_{dp}(p',q')$.

$$l_{m,t}(\theta) = \Pr_G(x_{p',q'}, y_{p',q'}, \theta) * \frac{1}{\sqrt{2\pi} h_{\theta,P}} \exp\left\{ -\frac{1}{2}\left(\frac{\theta - \theta_{m,t,i}}{h_{\theta,P}}\right)^2 \right\}$$

$$l'_{m,t}(v) = \frac{\exp\left\{ -\frac{(v - v_{mean}(p',q'))^2}{2v_{\mathrm{var}}(p',q')} \right\}}{\sqrt{2\pi * v_{\mathrm{var}}(p',q')}} * \frac{\exp\left\{ -\frac{(v - v_{m,t,i})^2}{2v_{dp}(p',q')} \right\}}{\sqrt{2\pi * v_{dp}(p',q')}}$$

where $h_{\theta,P}$ is the standard deviation about the angle of particles.
In addition, we make the cumulative density functions of $l_{m,t}(\theta)$ and $l'_{m,t}(v)$, defined as follow equations, $L_{m,t}(\theta) = \int^{\theta} l_{m,t}(\theta)\, d\theta$ and $L'_{m,t}(v) = \int^{v} l'_{m,t}(v)\, dv$, and generate two types of random numbers, $r_\theta (0 \le r_\theta \le L_{m,t}(2\pi))$ and random number $r_v (0 \le r_v \le \lim_{v_{\max}\to\infty} L'_{m,t}(v_{\max}))$. So, we decide the direction $\theta_{m,t+1,i}$ and velocity $v_{m,t+1,i}$ $t+1$ frames after scattering by evaluating θ which satisfies $r_\theta = L_{m,t}(\theta)$ and v which satisfies $r_v = L'_{m,t}(v)$.

2.1.3 Definition of Connection Cost

Finally, we explain about the definition of connection cost $Cost(i,j)$ between $Traj\ i$ and $Traj\ j$. When the number of the particles scattered from the end point of $Traj\ i$ is N_P, $Traj\ j$, the start point is $P_{j,S}(x_{j,S}, y_{j,S})$ and the direction of velocity vector at $P_{j,S}(x_{j,S}, y_{j,S})$ is $\theta_{j,S}$, appears T frames after the disappearance of $Traj\ i$, we define $Cost(i,j)$ as follow equation after evaluating the distribution of probability density $\Pr_{i,j}(x_{j,S}, y_{j,S}, \theta_{j,S})$ of N_P particles at $P_{j,S}(x_{j,S}, y_{j,S})$ using kernel density estimation method as before.

$$\Pr_{i,j}(x_{j,S}, y_{j,S}, \theta_{j,S}) = \frac{1}{N_P}\sum_{m=1}^{N_P} \frac{\exp\left\{ -\frac{1}{2}\left(\frac{(x_{j,S} - x_{m,T,i})^2}{h_x^2} + \frac{(y_{j,S} - y_{m,T,i})^2}{h_y^2} + \frac{(\theta_{j,S} - \theta_{m,T,i})^2}{h_\theta^2} \right) \right\}}{(2\pi)^{3/2} h_x h_y h_\theta}$$

$$Cost(i,j) = 1 - \Pr_{i,j}(x_{j,S}, y_{j,S}, \theta_{j,S})$$

2.2 Combinatorial Optimization

Next, we will explain about the method of detecting the optimum matching to minimize the sum of connection costs between the fragmentary trajectories defined in 2.1. In this research, we substitute the detection of optimum matching of the fragmentary trajectories to minimize sum of the connection costs in global for the detection of the optimum matching of the weighted bipartite graph in graph theory. Bipartite graph is the graph that all the included nodes are divided into two groups and all the arcs exist only between the nodes belonging to one group and the nodes belonging to the other group, weighted bipartite graph is the bipartite graph that all the arcs have the attached weights.
First, when there are N_T trajectories, we make the weighted bipartite graph that include $2N_T$ nodes described as the trajectories, that is to say, the number of one group of nodes is N_T and N_T

nodes correspond to N_T trajectories. The weight of the arc between *Node i* and *Node j* in the weighted bipartite graph is defined as $Cost(i,j)$ and the capacity of that is defined as $Cap(i,j)$. Here, in advance, we set the threshold $CostThresh$ about the connection of costs and the threshold $FrmThresh$ about the difference of frames between the frame when the end point of $Traj\ i$ is observed and the frame when the start point of $Traj\ j$ is observed. We judge whether we make the arc between $Node\ i$ and $Node\ j$ or not by these two thresholds. If $Cost(i,j) \geq CostThresh$ or $T \geq FrmThresh$, we don't make the arc between *Node i* and *Node j*. Second, we make *Node S* that is connected to all the nodes of one group and *Node T* that is connected to all the nodes of the other group, where for any *i, j*, $Cost(S,i) = Cost(j,T) = 0$, $Cap(S,i) = Cap(j,T) = 1$. Lastly, we set the quantity of water Q, regard the weights of the arcs as the costs to flow water and detect the optimum network flows from *Node S* which means the source to *Node T* which means the sink to minimize the sum of the costs of the detected network flows. In Figure 1, we show the conceptual image of the weighted bipartite graph to detect the optimum matching of the fragmentary trajectories.

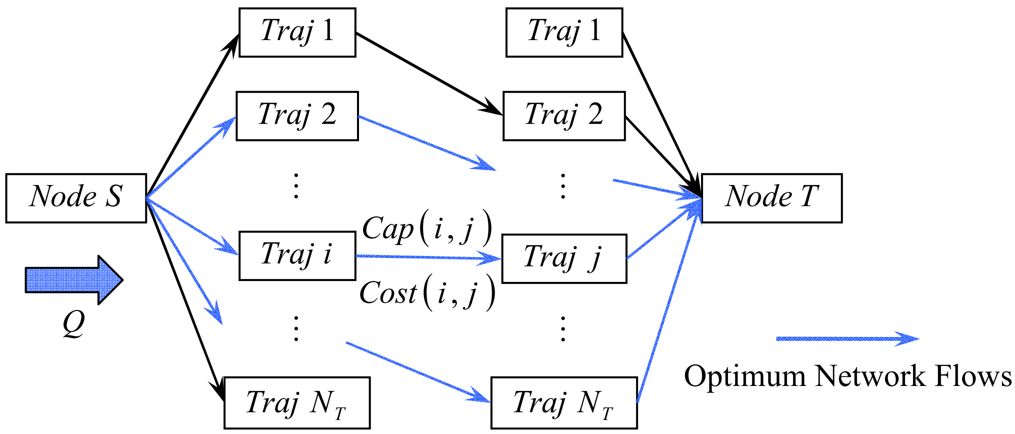

Figure 1 Conceptual Image of the Weighted Bipartite Graph

For example, as the result of combinatorial optimization, the flows between *Traj* 1 and *Traj* 3, *Traj* 3 and *Traj* 5 are detected, we can restore the movements of pedestrians described as *Traj* 1, *Traj* 3 and *Traj* 5. In this research, we used the Ford-Fulkerson Algorithm to detect the optimum network flows of the weighted bipartite graph. Please refer to (B.Korte, 2005) in detail.

3. EXPERIMENT

In this section, we will describe the experiment whose objective is to track the movements of pedestrians using laser range scanners, performed at the concourse of the railway station in Tokyo in June of 2006.
The concourse where the experiment was performed is about 30 meter-by 60 meter and occupied with over 200 pedestrians. Laser range scanners used at the experiment are LMS-200 made by SICK Inc. in Germany and the number of laser range scanners used at the experiment is eight. This laser range scanner measure the distance by time of flight of laser ray and the maximum distance of measurement is 30 meter. The scan rate of laser range scanner is determined by the angle we measure and the resolution of angle. In this experiment, the scan rate is 37.5Hz. We show the plane figure of the concourse and the layout of laser range scanners in Figure 2.

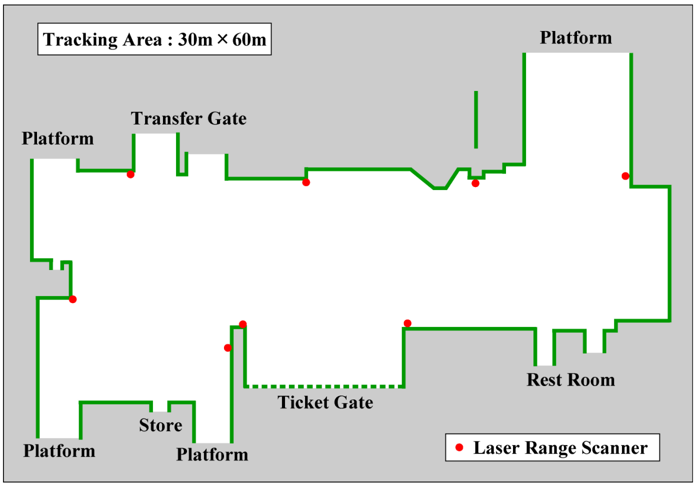

Figure 2, Plane Figure of the Concourse and the Layout of Laser Range Scanners

In this research, we try to restore the fragmentary trajectories of all pedestrians tracked from AM07:00 to AM07:05 per 0.5 second at the rush hour by applying proposed methods to the fragmentary trajectories. Here, the spatial data we use to try to move particles is made from the trajectories tracked from AM08:00 to AM08:05 at the same space. In addition, we made the ground truth about the connection of the fragmentary trajectories from AM07:00 to AM07:05 by tracing the movements of all pedestrians by our eyes in advance and verify the accuracy of proposed method by comparing the ground truth with the result of restoration of the fragmentary trajectories by proposed method.

4. RESULT

4.1 Accuracy Index

When there are N_T trajectories, we make the Connection Map which includes the connecting trajectory ID of the ground truth and these of the result of restoration by proposed method and we judge true or false by comparing the ground truth with the result of restoration. In Table 1, we show the example of Connection Map. Here, if a certain trajectory doesn't connect to any trajectories, the section of "Connecting *Traj* ID" in Connection Map is described as "Not Connect".

Table 1, Example of Connection Map
("GD" means "Ground Truth", "RR" means "Result of Restoration")

Traj ID	Connecting *Traj* ID (GD)	Connecting *Traj* ID (RR)	True or False
1	1'	1'	True
2	Not Connect	Not Connect	True
3	3'	3''	False
4	Not Connect	4''	False
⋮	⋮	⋮	⋮

So, we define the accuracy index $AI(\%)$ as follow equation.

$$AI(\%) = A/N_T * 100$$

where A is the number of "True" in Connection Map.
That is to say, $AI(\%)$ means the percentage of the trajectories whose connecting trajectory IDs of the result of the restoration are in accord with the ground truth.

4.2 Result

We show the parameter setting of each variable for verifying the accuracy of proposed method in Table 2 and the accuracy index $AI(\%)$ at these parameter settings is as follows.

Table 2, Parameter Settings

Parameter	Value	Parameter	Value
h_x	9.01	N_P	100
h_y	9.01	Q	204
h_θ	1.20	$CostThresh$	0.99945
$h_{\theta,P}$	1.20	$FrmThresh$	15

$$AI(\%) = 90.5 \text{ , where } N_T = 581 \text{ and } A = 526$$

5. CONCLUSION AND FUTURE WORKS

5.1 Conclusion

Section 4.2 proves that we can connect over 90 percent of the fragmentary trajectories correctly and restore the movements of pedestrians by proposed method. That is to say, proposed method has enough effectiveness to help us understand the flows of pedestrians in a certain space.

5.2 Future Works

Proposed method has a problem that connection of the fragmentary trajectories is a one-to-one correspondence. So, proposed method can't connect the fragmentary trajectories correctly in the case that several trajectories are integrated into one trajectory because pedestrians draw together and in the case that the integrated trajectory is separated into several trajectories. For future works, we can make it possible to detect the number of pedestrians integrated into a certain trajectory. This leads to a marked increase of accuracy of proposed method. The number of pedestrians integrated into a certain trajectory is applicable to proposed method as a capacity of arc in the weighted bipartite graph in section 4.2 Combinatorial Optimization.

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