Spatial and Temporal Visualization of Pedestrians Based on Walking States

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***Abstract*—People flow has useful knowledge in various fields including traffic, disaster prevention, and marketing. Such information can be obtained by looking for the movement patterns of each person and the features of each place.**

We have proposed a visualization method that summarizes the paths of a large number of pedestrians in order to discover their useful information. However, we have not been working on visualization focusing on walking states whether people are moving rapidly or slowly. This paper presents a visualization method based on the walking states of a large number of pedestrian paths measured by using cameras. The visualization tool allows users to inspect walking people based on walking states from spatial and temporal views. The spatial view applies a heatmap and the temporal view adopts a stacked line graph. In addition, the user interface has a function to simultaneously visualize changes in the walking state distribution over time and walking paths.

***Index Terms*—visualization, people flow, walking state**

I. Introduction

Walking people can be measured by various devices such as GPS data and video. Among them, camera-based measurements of people flow lines are expected to be widely used in the future because pedestrians do not have to have any devices. Also, camera-based measurements can record relatively accurate positions of walking people. People flow line data have been utilized for various fields because the data has much useful knowledge. It is worth analyzing the videos to discover movement patterns and features of the people, since we can discover fruitful knowledge to solve many social problems. For example, we can establish better evacuation routes, find causes of traffic jams ,and design product displays that attract more customers by means of the analysis of people flow data.

Here, we need to get people flow data recorded for a long time and in large space in order to realize such analysis. However, it is often a very complicated and bothering task to discover useful knowledge from the people flow data because a large number of people flow lines may be contained. Moreover, data owners who have experienced at the spot do not always have enough time and advanced knowledge for human flow analysis. Comprehensive visualization of people flow data enables many users who do not have the expert knowledge to analyze the data efficiently.

We found that visualizing and summarizing the walking paths is not enough just to understand the intention of pedestrians. It is important to consider the walking status of each pedestrian, especially in a space where various types of pedestrians are mixed. Here, walking status means a variety of semantics and movements of the pedestrians in this paper. Typical examples of the walking status include walking while glancing at something, walking slowly while staring at something, or walking straight and quickly forward a destination. Our goal is to propose a visualization tool that represents the statistics of walking states since most of the existing visualization techniques just represent a set of walking paths by drawing a set of lines.

We have proposed a visualization method [1] that summarizes the walking paths after compressing the trajectories of a large number of pedestrians. However, our previous method did not show walking states whether people are walking rapidly or slowly.

This paper presents a technique that classifies the flow data based on the walking states of a large number of pedestrian paths before visualizing them. Here, our current study simply defines the walking states by walking speeds.

Our goal is the development of a visualization system satisfying the following tasks:

- T1: Visualize the spatial distributions of walking states.
- T2: Visualize the temporal changes of the distributions of walking states.

To realize the above tasks, the presented technique firstly divides the whole area taken by cameras into small rectangular subareas and aggregates the number of pedestrians who pass

2375-0138/20/$31.00 ©2020 IEEE
DOI 10.1109/IV51561.2020.00099

through each subarea for each walking state. We define the distribution of the number of walking people by each subarea and walking state as walking state distribution in this paper. The technique realizes **T1** by drawing the distributions of walking states of each subarea as a set of stacked bar charts instead of drawing all the walking routes. This representation solves the problem of conventional line-drawing-based visualization techniques that stationary pedestrians are displayed as dots and therefore they are difficult to be found. In addition, the technique applies a stacked polyline chart to realize **T2**. This representation makes us observing how the distribution of walking states changes and picking up at noticeable time periods. These visualization components can represent pedestrians based on walking states including stationary states. It could be useful for people who want to stop and know what time and place they are paying attention to, such as convenience stores and museums.

II. Related Work

This section introduces existing studies to analyze and visualize trajectories of pedestrians and non-pedestrians.

Many existing methods classify and visualize spatio-temporal people flow data recorded as real values. Also, there have been many existing visualization methods to display the space where the walking paths are measured and to draw lines (or figures) representing the walking paths directly in a display space. As an example, Yabushita et al. [2] proposed a technique that summarizes similarly shaped walking routes of a large number of people who pass through particular subareas at open spaces where there are no prescribed roads. This path drawing method realizes better comprehensibility for many trajectories recorded in a place where pedestrians can move freely; however, this method does not visualize focusing on the stationary states because stasis people are drawn by not lines but dots.

There have been a variety of visualization methods other than directly drawing lines of walking routes. Matsumoto et al. [3] proposed that the six items in the people flow line analysis be visualized simultaneously by drawing points, lines, and planes on a three-dimensional map. This tool enables easy comparison of each walking status in different places at the same time. Wang et al. [4] presented a visualization method using a map and a string graph that connects the starting and arriving points of taxis in urban areas in order to analyze the people flow in such areas and to estimate the travel time. This technique realizes better comprehensibility by using not a chord graph but a large number of trajectories on a map. Liu et al. [5] proposed a visualization technique that represents the stationary states of people by combining a Voronoi diagram and a heatmap to analyze the distribution of people entering immovable spaces such as trains and elevators. However, it is difficult to observe the details of walking records by using these methods that are specialized in summarizing and representing walking paths, since these methods do not draw human flow itself. Also, all of these are visualization techniques only for pedestrians in a particular moment, and do not represent temporal changes for a long time. According to the above discussion, we found a solution that combines the above three approaches to representing a large number of walking paths and their temporal changes.

Linking multiple views is an effective approach to visualize complex datasets. Visualization systems linking multiple visualization elements are called "Linked View" and have already been applied to various application domains of visualization techniques. Guo et al. [6] proposed a simultaneous visualization method that the traffic lines of driving cars on the road are visualized from three viewpoints including space, time, and multi-dimensional attribute values. Miyazaki [7] proposed a method to visualize the people flow by calculating probability density and vector fields at the same time. This method enables users to overlay two types of visualization and analyze walking data from multiple viewpoints. These methods are common to our study since they apply linked views. Meanwhile, our study differs from the above two methods in targeting walking path data in open spaces that fixed paths are not specified.

Minemoto et al. [8] classified the walking state into three types: direct, route search and goal search, and proposed a method for drawing walking paths that represent the walking states by a variety of touches of lines. Although this method is a visualization method that enables users to easily understand walking states because walking people are represented only as lines, it does not represent stationary states effectively. Meanwhile, we are developing a visualization method that focuses on both pedestrians' movement and stationary states in this study.

Services for visualizing people flow for general users have also been released recently. As an example, A service called “Ekishi-Vision [9]” has been released by Tokyu Corporation. This system displays the degree of congestion on the platform and near the ticket gates in real-time, distributing from Tokyu Line App. However, such services differ from our study in specializing in visualizing real-time human flow.

III. Presented Visualization Tool

This section presents the processing flow and detailed description of the technical components of the presented technique. We adopt not 3D- but 2D-visualization because 2D-visualization is convenient to use without specifying appropriate viewpoints. We applied the environment of recording people flow data as reported by Miyagi et al. [1]

A. Recording People Flow Data

We define that a record of people flow data includes the following information:

- Timestamp that the position of a pedestrian is measured.
- ID of the pedestrian.
- Position of the pedestrian in a 2D space (x, y).

We can form a trajectory of a particular pedestrian by collecting the records which have the particular ID corresponding to the pedestrian, and then chronologically ordering the collected records. Our current implementation uses a motion capture device Xtion to measure the position of the head of

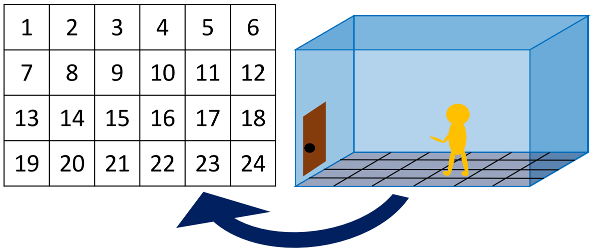


Fig. 1. Symbolic map for visualization.

the pedestrian in a 3D space and records them converting into a 2D space. This implementation assigns a particular ID to each pedestrian, and measures positions of heads of pedestrians every one millisecond. Remark that it regards as another pedestrian when he/she exits the camera frame and then gets into the frame again; therefore, the same person may be counted as multiple persons. We deal with the trajectories in a 2D space corresponding to the floor of the real space because changes in heights of the pedestrians' heads do not affect while determining the walking states.

B. Visualizing the Distribution of Walking States in All Subarea

The technique classifies the walking states of the pedestrians and then visualizes the statistics of the walking states for each subarea dividing the floor taken by the camera. Our current implementation determines the walking states simply based on the walking speeds.

We firstly symbolize and divide the floor taken by a camera to construct a symbolic map (for example as shown in Fig. 1) and aggregate the pedestrians who have moved forward, backward, left and right from each subarea of the floor. Here, the setting of an appropriate number of the subareas depends on the shape and size of the floor and the resolution of the display used for the visualization. We preferred to divide the floor so that subareas are shaped square and appropriately sized. Fig. 1 illustrates that the floor is divided into 24 subareas. Therefore, we aggregated the number of pedestrians for 96 types of movements since the 24 subareas have four movement directions including forward, backward, left and right.

In the current implementation, the walking states are simply classified based on the walking speeds. Specifically, we apply the following processes.

1) Calculate the speed of each pedestrian in each subarea.
2) Calculate the average speed per second if the walking person is in the same subarea as one second before.
3) Continue this calculation until the pedestrian moves to a different area.
4) Calculate the speed and direction of the movement in each subarea if a pedestrian moves to different subareas every second.
5) Classify the speed of the person into one of the four levels and specify as the walking state value.

The four-level walking state values indicate stationary / slow walking / normal walking / fast walking. The thresholds of the walking state values are defined based on the research by Sasaki et al. [10] Also, we assign unique colors to the walking state values by applying the color map shown in the TABLE I. Specifically, people whose walking speed is slow are represented in red or yellow, and those who are fast are represented in green or blue.

TABLE I
RELATIONSHIP BETWEEN WALKING STATE VALUE AND COLOR

Color	Walking State Value	Speed[m/s]
Red	1	∼ 0.1
Yellow	2	0.1 ∼ 0.45
Green	3	0.45 ∼ 0.75
Blue	4	0.75 ∼

Next, we count the number of people for each walking state value in each subarea. The technique visualizes the statistics of pedestrians for each walking state and movement direction in each subarea.

Our representation of the distribution of walking states is as follows. Gray squares are placed at the centers of subareas, and four-color stacked bar charts are drawn in the upper, lower, left and right side of the squares. The stacked bar chart in each direction is drawn in the colors assigned to the walking state values. The sizes of the charts depict the number of pedestrians in each walking state.

C. Visualization of Temporal Change of Walking State in All Subareas

In addition to the representation described in Section III-B, we visualize the temporal change of the number of pedestrians of each walking state in all subareas as a stacked line chart. This visualization represents the total number of walking people of each walking state in each period (one minute in the current implementation) for all subareas as shown in Fig. 1. Our implementation counts the number of pedestrians by the number of unique pedestrian IDs. The total number of counted IDs may be larger than the actual total number of participants since multiple IDs may be assigned to the same person as explained in Section III-A. The color assignment is based on the color map shown in TABLE I, as applied by another visualization described in section III-B.

D. Visualization of Temporal Change of Walking State in the User-Selected Subarea

Our implementation prepares walking route files for each subarea and records the walking routes that pass through the subareas to the corresponding files. The implementation loads the file corresponding to a subarea when a user selects it and displays the walking routes described in the opened file. As an example, when it is divided into 24 subareas as shown in Fig. 1, the implementation creates 24 files, and different files are opened in accordance with the selected area. It means 24 different drawing results can be shown. Our implementation represents walking paths as individual lines

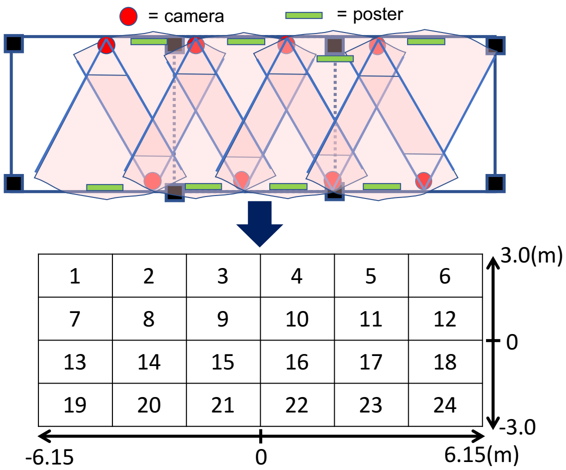


Fig. 2. Visualization map in poster presentation venue.

without summarizing as a small number of bundles. It does not distinguish the moving directions in order to keep simpler representations.

E. Visualization of Walking Paths After Passing through the User-Selected Subarea

We count the change in the number of pedestrians of each walking state for each subarea (24 places in total in the example of Fig. 1). The movement direction is not taken into account while counting. The color assignment is based on the color map shown in TABLE I, as applied by another visualization described in section III-B.

IV. Visualization Examples

A. Experiment Settings

We visualized a people flow dataset recorded at the poster presentation venue of a joint laboratory meeting held in 2017 using the proposed methods. Fig. 2 shows the layout of the venue where the dataset was recorded. We divided into 24 subareas as shown in Fig. 2 as a result of our own trial and error. Red points in this figure depict the locations where Xtion is installed. Green rectangles at both sides of the room wall (upper and lower ends in Fig. 2) depict positions of posters. The central parts of this room are passages. A poster session at the meeting consisted of eight presenters, and five sessions every one hour were held. We recorded this dataset with 40 participants without stopping for five hours. The dataset was divided into five files corresponding to one hour. This section introduces the visualization results of particular temporal periods.

B. Visualization Examples

Fig. 3 shows an example of visualizing the distribution of walking states and temporal change in all subareas by applying the methods described in Sections III-B and III-C. The left side of Fig. 3 shows the spatial distribution of walking states in all subareas and the right side of Fig. 3 shows the temporal change of the distribution of walking states in all subareas. The color assignment is based on the color map shown in TABLE I. The larger the drawing subarea is, the larger the number of passed pedestrians in the subarea is.

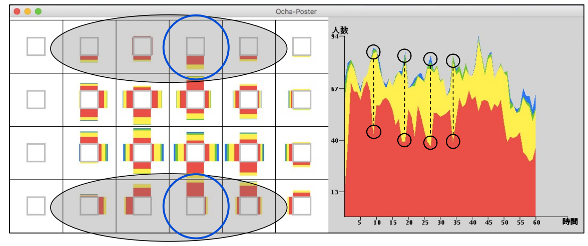
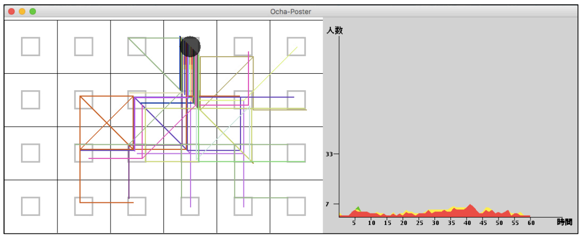


Fig. 3. Visualization of walking state distribution in all areas.

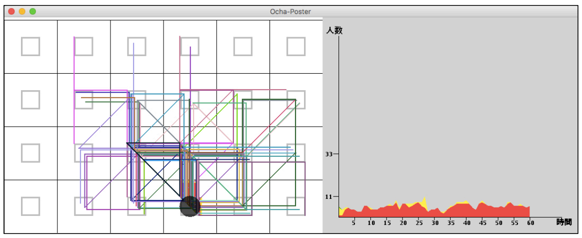
Fig. 3 illustrates that walking speeds of pedestrians are totally slow. We estimate the reason is that a large number of people participated in the poster session in a narrow space where it was difficult to pass each other. Meanwhile, the left side in Fig. 3 illustrates that almost everyone was stationary because many people listened to poster presentations on the wall sides. On the other hand, the visualization result illustrates that many people walked more speedy at the central passage. Visualization of four walking directions makes users easy to understand not only the speeds of pedestrians but also their moving direction intuitively. The sizes of the stacked bar charts indicate that the numbers of pedestrians vary depending on the positions of posters. For example, in the subarea surrounded by the gray circle in Fig. 3 (left), many people stop at subareas in the lower side of the visualization result because the red bars of the stacked bar charts are larger than at subareas in the upper side. We estimate the reason is that there was a doorway at the lower right side in the left side of Fig. 3 and a larger number of people saw the poster presentation in the subareas at the lower side.

Lastly, the black circles at the right side in Fig. 3 illustrate that walking states have changed significantly. Specifically, the number of stationary participants indicated by red bars decreased while the number of other participants indicated by yellow, green and blue bars increased about every five minutes. This suggests that poster presentations were over and many participants moved to another poster about every five minutes.

Fig. 4 shows an example of selecting a particular subarea and simultaneously visualizing walking paths. Also, the figure shows the temporal changes in walking states in the subarea by applying the representations described in Sections III-D and III-E. The stacked line graph in Fig. 4 (right) illustrates the temporal change of walking states over time in the selected subarea and many lines shown in the left side of Fig. 4 represents paths of pedestrians after passing through the selected subarea. These visualizations illustrate that the ratios of the walking states changed over time. Simultaneous visualization of temporal change of walking states and walking routes makes it possible to compare the change of the number



(a) Select area 4.



(b) Select area 22.

Fig. 4. Simultaneous visualization of time change of walking states and walking routes in selected area.

of people over time and the routes of pedestrians who pass the selected subarea.

Fig. 4 (a) and Fig. 4 (b) show the visualization results when a user selected the subareas enclosed by the blue circles in Fig. 3. Fig. 4 (a) is a visualization when a user selected the upper blue circle (area 4 of figure 2). Fig. 3 (b) is a visualization when the lower blue circle (area 22 in Fig. 2) is selected. Two subareas encircled by blue lines in Fig. 3 are almost symmetry; however, the walking routes in the two subareas in Fig. 4 differ greatly. Specifically, many pedestrians who have passed through the subarea 4 shown in Fig. 4 (a) move backward (downward in the visualization result), whereas a lot of pedestrians who have passed through the subarea 22 shown in Fig. 4 (b) move not only in the forward (upward in the visualization result) direction but also in the lateral directions. Drawing such walking paths can promote to understand these detailed movements of pedestrians. Also, the stacked line graph in Fig. 4 (right) shows that a larger number of pedestrians passed the particular subarea as shown in Figure 4 (b) rather than another time period shown in Fig. 4 (a).

C. Discussion

One of the essential issues is the design for drawing the walking routes. The current implementation assigns colors and positions of polygonal lines randomly in order to prevent the polygonal lines representing multiple walking paths to reduce the overlaps of lines that may worsen the comprehensibility of visualization results. This drawing method has a problem that the visualization results may fluctuate. We would like to adopt a method for drawing walking routes presented by Minemoto et al. [8]

Another issue is that we need to adjust the amount of walking paths to be drawn. The current implementation for drawing walking route drawing displays all the routes stored as walking data. It may cause a serious amount of overlaps of the lines that may worsen the comprehensibility. We could like to cluster walking paths and display only characteristic walking path clusters to solve this problem.

The division of movement directions at each subarea is also an important factor for our visualization. Many studies on the analysis of people flow have classified the moving directions of pedestrians into eight directions including not only forward, backward, left and right but also oblique directions. The movements to the diagonally adjacent subareas are deleted from the visualization result in the current implementation; however, drawing walking routes in selected subareas includes the diagonal direction. Actually, the visualization results illustrate that some pedestrians directly moved to diagonally adjacent subareas. This fact causes inconsistency between the two visualization results. The current implementation has four basic directions to avoid the complication of the visualization views. Therefore, we would like to visualize the number of pedestrians in eight directions including the diagonal directions while visualizing the number of pedestrians for each walking state for all subareas.

Finally, it is essential to support the visualization of long-term walking datasets as one of the goals of this research. Specifically, we would like to support a user interface that allows users to select a particular period or subarea that he/she wants to observe in detail from long-term walking datasets.

V. Conclusions and Future Work

In this paper, we proposed a technique to visualize a large amount of walking data in a wide area and for a long time captured by multiple cameras. We classify the walking states based on the walking speeds of pedestrians and visualize the distribution of walking states of the pedestrians in the region taken by the cameras. Furthermore, a linked visualization of the temporal change of walking states and walking routes enables the observation of the change of walking states.

This method enables us to understand the overview of the walking states from the distribution of walking states in all subareas. Walking states of all pedestrians for each subarea could be represented exhaustively by applying stacked bar charts to visualize the existence of stationary pedestrians that cannot be represented only by walking paths. Also, the visualization of temporal change of the distribution of walking states and walking routes in the user-selected subareas enables to observe temporal changes of walking states at particular locations. We represent the walking routes after passing through each subarea because they are not represented by the stacked bar charts that draw the distribution of walking states.

It is not always sufficient and appropriate to classify the walking states only based on walking speeds. Taking the poster presentation hall as an example, we cannot determine whether pedestrians are watching the poster presentations or they are just chatting, even they have the same stationary state. This is a limitation of our current implementation that classifies walking states only from the coordinate values of the walking routes. We would like to analyze the input movies to appropriately determine the walking states in the future.

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