# Measuring Microscopic Flow Performance for Pedestrians 

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#### Abstract

A paradigm to improve the quality of pedestrian movement by considering their interactions in the microscopic level is introduced. By this approach, design of pedestrian facilities is not merely space allocation but it can also utilize other form of flow controls in space, time and direction. Although microscopic pedestrian analysis exists, the microscopic pedestrian data collection has not been developed. Once such microscopic data is collected, another problem on how to measure the flow performance from the microscopic data collection arises. This paper describes how data reduction can be made to obtain pedestrian flow performances. The automation of microscopic pedestrian data from video files is also explained. The video data is converted into numbers as a NTXY database. Following this conversion, the rest of the process can be done using computers that reduce the processing cost and speed, and improve accuracy. The data reduction of NTXY database into well-established traffic flow variables and some prominent flow performance was formulated. It was confirmed that the procedures described have significant potential to automate measurement of both microscopic and macroscopic pedestrian flow performances.


## Introduction

Increased awareness of environmental problems and the need for physical fitness encourage the demand for provision of more and better pedestrian facilities. To decide the appropriate standard and control of pedestrian facilities, pedestrian studies need to be done. Pedestrian studies consist of pedestrian data collection and analysis.

Most of the pedestrian studies that have been carried out are on a macroscopic level. Macroscopic pedestrian analysis is first suggested by Fruin (1971) and followed by HCM (1985). While the macroscopic pedestrian data-collection is recommended by ITE (1994) wherein all pedestrian movements in pedestrian facilities are aggregated into flow, average speed and area module. The main concern of macroscopic pedestrian studies is space allocation for pedestrians in the pedestrian facilities. It does not consider the interaction between pedestrians and is not well suited for prediction of pedestrian flow performance in pedestrian areas or buildings with some objects (kiosk, seating, telephones, fountain, etc.).

Recently, with the development of microscopic pedestrian analysis, a paradigm shift to improve the quality of pedestrian movement became a new goal (i.e. Lovas, (1994); Blue and Adler (2000)). Instead of merely allocating a space for pedestrian, the movement quality of pedestrians is also considered. The movement quality of pedestrians focuses on comfortability in walking and efficiency. In macroscopic pedestrian studies, given a number of pedestrians and a level of service, the model may give the space allocation. In the microscopic level, however, given the same number of pedestrian and the same space, with better set of rules and detailed design, a better flow performance may be produced. Space of the pedestrian facilities is only one type of pedestrian flow control in the microscopic level. This more comprehensive pedestrian-flow control happens because microscopic pedestrian studies consider pedestrian interaction. Pedestrian interaction is the repulsive and attractive effect among pedestrians and between pedestrians with their environment. Since the movement quality of pedestrians can be improved by controlling the interaction between pedestrians, better pedestrian interaction is the objective of this approach.

Figure 1 shows the system approach to improve the movement quality of pedestrians.

Pedestrian interaction can be measured and controlled. Pedestrian flow performance is defined as the indicators to measure the interaction between pedestrians. The pedestrian interaction can be controlled by time, space and direction. Pedestrians may be allowed to wait for some time, or walk at a particular space (e.g. door) or right of way (e.g. walkway), or at certain directions. Case studies using microscopic simulation as reported by Helbing and Molnar (1997) and Burstedde et al (2001) shows that the flow performance of pedestrians in the intersection of pedestrian malls and doors could be improved by putting some control such as roundabout or direction rule. More efficient pedestrian flow can even be reached with less space. Those simulations have rejected the linearity assumption of space and flow in the macroscopic level. The analytical model for microscopic pedestrian model has been developed by Henderson (1974) and Helbing (1992), but the numerical solution of the model is very difficult and simulation is favorable.

Therefore, to improve the quality of pedestrian movement, microscopic pedestrian studies are needed. In microscopic pedestrian studies, every pedestrian is treated as an individual and the behavior of pedestrian interaction is measured.

Though microscopic pedestrian analysis exists through simulation, the microscopic pedestrian data collection has not been developed. Measurements of microscopic flow performance in the real world need to be elaborated in parallel with the automation of data collection. The outputs of microscopic pedestrian simulations also need to be compared with the real world data. These comparisons are not possible without the ability to measure individual pedestrian movement. Since a large amount of data may be needed, data collection procedures should be automated.


Figure 1. Paradigm shift to improve the quality of pedestrian movement. Source: Authors' figure.

Once such microscopic data is collected, another problem on how to measure the flow performance from the microscopic data collection arises. The results of microscopic data collection are the locations of each pedestrian at each time slice. These huge data need to be reduced into information that can be readily understood and interpreted. This paper describes how data reduction can be made to obtain pedestrian flow performance. The automation of microscopic pedestrian data from video files is also explained.

Those measurements are also useful for the evaluation of pedestrian facilities, before and after studies, design experiments in the field, and measurement of movement behavior of pedestrians. The study is still only restricted to pedestrians without considering vehicular - pedestrian interaction.

The remainder of the paper is systematized as follows. The next section describes the output of microscopic data collection called NTXY database. After that, to be able to interpret the NTXY database, pedestrian flow-performance is formulated. Subsequent section presents the method to automate the data collection from video files to obtain NTXY database followed with some discussion on results of the video data collection and flow performances.

## NtXY Database

Suppose each pedestrian can be represented by one point and tracking toward the movement of this pedestrian is done continuously from the time each pedestrian enters a system until it goes out of the system. The location of each pedestrian at each time is recorded continuously and stored into a database of pedestrian movement. Using such kind of database, the movement behavior of pedestrians can be viewed back and measured.

Such kind of continuous pedestrian database is an ideal database that is difficult to be developed. A sampling approach, however, can be done by two systems, which is microscopic pedestrian simulation model (MPSM) and microscopic video data collection (MVDC). The coordinate location of each pedestrian is tapped for every discrete time. The digitalization is performed, for example 30 samples per second, with a uniform time interval. The discrete pedestrian movement database produced from this digitalization process is called the NTXY database.


Figure 2. Digitalization of pedestrian movement database. Source: Authors' figure
This digitalization process is important as we convert from an analog system into a digital system. In traditional video data collection, a video is taken from the real world and manual work is done to count the number of pedestrian in the laboratory. When another data (e.g. speed) is needed, manual work is performed repeatedly toward the same video. Those manual works are not only expensive and exhaustive but also reduce the accuracy of the data due to manual search. The same person using the same data may obtain different results. Using the NTXY database, the movement data of pedestrian in the video are converted into numbers. The rest of the process can then be done by a computer, which reduces the processing cost and improves accuracy and speed. The same result is always gathered for the same data.

As shown in

Figure 2, the NTXY database can be created by any microscopic pedestrian simulation model and microscopic video data-collection system. Both continuous and discrete based simulator can record the movement data of each pedestrian at every constant interval and write them into a text file. Pedestrian flow performance is calculated based on the NTXY database. Whether the data comes from the real world or from the simulation models, the flow performance can be calculated with the same definition. If the design of pedestrian facilities is changed, in either real world or simulation, a new NTXY database is produced. By comparing the flow performance before and after the design change, a better design can be revealed. In this case, the flow performance functions as a design criterion for the facilities. It gives feedback for better design.

The video data collection is related to the simulation through NTXY database. Real world data is captured and digitized by the MVDC into a NTXY database. Using a simple viewer program, this database can be viewed back as a simulation of the real world.


Figure 3. NTXY database. Source: Authors' program
Figure 3 shows the part of a NTXY database. Each row in the database represents a single digitized sample. It is an observation point where the position of a pedestrian at a time is recorded. The database consists of four fields, which are pedestrian number, time and coordinate location. Pedestrian number is a unique number for each pedestrian and a new pedestrian number is given to a new person who enters the system. This number is useful to distinguish the data of a pedestrian from another. Since the time interval of the sampling is constant, the time field in the database can be represented as an integer instead of a real number. This representation is used to reduce the amount of memory to store the database. The coordinate location of each pedestrian is the real world coordinate. The reference point of the coordinate system is arbitrary but fixed within the system.

Conversion of integer time, $T$, into the real time, $R_{T}$, depends on the sampling interval dt. It is a difference equation with initial value of zero and the particular solution is given by the simple equation below,

$$
\begin{equation*}
\mathrm{R}_{\mathrm{T}}=\mathrm{T} . \mathrm{dt} \tag{1}
\end{equation*}
$$

## Flow Performance

The idea of flow performance was used by the TRANSYT software (Vincent, R.A. et al (1980)) to determine the performance of a traffic network. It used weighted vehicle operating cost and delay as factors of the performance index. Helbing (1998) proposed a pedestrian flow performance to evaluate the simulation model using uncomfortability index and delay index. In this paper, both ideas have been advanced further.

Pedestrian flow performances are numbers that measure the efficiency of pedestrian flow. They measure direct or indirect ways of the interaction between pedestrians and the interaction between pedestrian with the environment. Direct ways mean measuring the interaction itself (i.e. distance between pedestrians). Indirect ways mean measuring the result of the interaction, instead of the interaction itself. Pedestrian delay for example is caused by the interaction. Better flow performance should aim for better pedestrian interaction and better pedestrian interaction is identical with a better quality movement for pedestrians.

Individual and average delay and uncomfortability indices, speed change, jerk, change of moving direction, are typical examples of pedestrian flow performance. They measure the result of the interaction among pedestrians and interaction between pedestrians with the facilities. They measure pedestrian interaction indirectly. Pedestrian flow performance is a broader concept than merely traffic flow variables. Since traditional traffic flow variables, such as pedestrian headway, flow, speeds and area modules also measure the interaction between pedestrian indirectly, they are also part of the pedestrian flow performance.

The pedestrian flow performance can be measured through distances, and angles of moving direction. It may be valued over time as a change of distances and angles (e.g. speed) or as a rate of change (e.g. acceleration), or as a rate of change of the change (e.g. jerk). They may be quantified for an individual at each time or toward other pedestrians nearby or against the boundary of the surroundings. Variation of ratios, indices and comparison toward some references may also produce different kinds of pedestrian flow performance. Since many kinds of pedestrian flow performances may be developed and recommended for further research work, only some prominent flow performances are discussed in this paper.

The following description illustrates the formulation of well-established traffic flow variables from the NTXY database. Individual and average delay and
uncomfortability indices are also specified. In the NTXY database, the location of each pedestrian number N at time T is recorded as ( $\mathrm{X}, \mathrm{Y}$ ). Using vector notation, the coordinate location of pedestrian N at time T is denoted as $\overrightarrow{\mathrm{X}}_{\mathrm{T}}$ because the pedestrian number N is obvious. The real time, when the pedestrian N is first and last recorded, is expressed by Ti and To respectively. Total number of observations, $\rho$, is the number of rows for pedestrian N in the database. The sampling time interval, dt , is a time gap between two recorded locations. Because the sampling time interval is constant, the relationship between the total number of observations, and the sampling time interval is expressed below.

$$
\begin{equation*}
(\rho-1) \cdot d t=\mathrm{To}-\mathrm{Ti} \tag{2}
\end{equation*}
$$

Walking displacement of pedestrian $N$ at time $T$ is denoted by $\vec{\delta}_{T}=\vec{X}_{T+d t}-\vec{X}_{T}$ while its straight-line displacement is represented by $\bar{\Omega}=\overline{\mathrm{X}}_{\mathrm{To}}-\overline{\mathrm{X}}_{\mathrm{Ti}}$. Table 1 shows several flow performance formulations for an individual pedestrian.

An ideal walking pace is assumed to be in a straight direction and at constant speed. Walking distance of pedestrian N in the system is a line integration of the motion path of the pedestrian. In discrete terms, it is the summation of path distances. Distance can be obtained by taking a norm toward its displacement. Average walking speed is the summation of the speed of pedestrian N at time T over time in the system divided by total number of sampling for that particular pedestrian. It also can be formulated as the average of walking distances in the system over time as shown in equation (4). Pace uniformity index measures the ratio between the real walking distance and its ideal walking pace. The index reaches one if the walking pace is uniform.

Table 1. Individual Pedestrian Flow Performance

| Pedestrian Flow Performances | Formula | Eq. |
| :--- | :--- | :--- |
| Walking distance in the system | $\omega=\sum_{\mathrm{t}=\mathrm{Ti}}^{\mathrm{To}-1}\left\\|\overline{\mathrm{X}}_{\mathrm{t}+\mathrm{dt}}-\overrightarrow{\mathrm{X}}_{\mathrm{t}}\right\\|$ |  |
| Average walking speed | $\mathrm{v}=\frac{\omega}{\mathrm{To}-\mathrm{Ti}}$ |  |
| Pace Uniformity Index | $\Psi=\frac{\\|\vec{\Omega}\\|}{\omega}$ |  |
| Uncomfortability index | $\gamma=\frac{\sum_{\mathrm{t}=\mathrm{Ti}}^{\mathrm{To}-1}\left\\|\bar{\delta}_{\mathrm{t}}-\frac{\bar{\Omega}}{\rho-1}\right\\|}{\omega \cdot(\rho-1)}$ |  |
| Delay | $\lambda=\frac{\omega-\\|\vec{\Omega}\\|}{\omega \cdot v}$ |  |

Source: Authors' formulation
Assuming that the most comfortable walking displacement is at an ideal walking pace, the variance of walking displacement is the measurement of the square deviation of walking displacement toward its ideal displacement. The deviation of
walking displacement toward average walking displacement is the norm of the difference between walking displacement with average walking displacement. However, a different length of walking distances may produce a different deviation. To avoid that problem, the walking distance is divided by the norm of the deviation as shown in (6). This deviation has a preferable characteristic that the value of the deviation will be zero if the walking displacement is uniform (constant speed) and in a straight direction. In other words, it measures the uncomfortable walking displacement, so it is called the individual uncomfortability index. Since the time interval between walking displacement is constant, the uncomfortability index also represents the speed and direction change.

Individual delay is the difference between the real travel time of pedestrians in the system and the travel time of a straight-line distance with constant average speed, divided by the walking distance. The unit can be time per distance (i.e. second per meter). The moving direction of an individual pedestrian is determined by her first and last locations. The direction can be represented as a unit vector that connects the point when the pedestrian enters and egresses from the system. The unit direction is formulated as

$$
\begin{equation*}
\stackrel{\rightharpoonup}{\mathrm{e}}=\frac{\stackrel{\rightharpoonup}{\Omega}}{|\vec{\Omega}|} \tag{8}
\end{equation*}
$$

Aggregation of the individual flow performance for all individuals is performed within a certain time interval, from $T_{1}$ until $T_{2}$. If $\kappa$ represents the total number of pedestrian in the system during the time interval, the aggregation of individual performance is simply an average toward the total number of pedestrians.

Table 2. Macroscopic Traffic Flow Variables

| Traffic Flow Variables | Formula | Eq. |
| :--- | :--- | :--- |
| Flow rate | $\mathrm{q}=\frac{\mathrm{K}}{\mathrm{T}_{2}-\mathrm{T}_{1}}$ | $(9)$ |
| Time mean speed | $\mathrm{TMS}=\frac{\sum_{\mathrm{N}} \mathrm{v}_{\mathrm{N}}}{\kappa}$ | $(10)$ |
| Space mean speed | $\mathrm{SMS}=\frac{\mathrm{L}}{\frac{1}{\kappa} \sum_{\mathrm{N}} \frac{\mathrm{L}}{\mathrm{v}_{\mathrm{N}}}}=\frac{\kappa}{\sum_{\mathrm{N}} \frac{1}{\mathrm{v}_{\mathrm{N}}}}$ | $(11)$ |
| Area module | $\mathrm{M}=\frac{\kappa}{\mathrm{A}}$ | $(12)$ |

Source: Authors' formulation
From the NTXY database and individual flow performances above, macroscopic pedestrian traffic flow variables are formulated. Table 2 shows the formulations of flow-rate, time mean speed, and space-mean speed and area module. Pedestrian flow rate is the total number of pedestrians passing a line in the system over a certain time interval. Time mean speed is the average of individual walking speeds while space mean speed is the average speed of all pedestrians occupying a given area in the
system over the time interval $\mathrm{T}_{1}$ until $\mathrm{T}_{2}$. It is also equal to the ratio of the number of pedestrians and the harmonic summation of average individual walking speed. Area Module is the area of the system divided by the total number of pedestrian in the system over specified time interval.

## Automation of Microscopic Data Collection

Lu et al (1990) developed a pedestrian counting device to gather macroscopic variables automatically. The researchers however, were limiting themselves to special background and special treatment of the camera location. Tsuchikawa et al (1995) used one-line detection as a development of photo-beam technology to count the number of pedestrians passing that line with a top view camera. Mori et al (1994) detected pedestrians from other objects based on the rhythm pattern of walking. Significant advancement of pedestrian motion analysis was recently developed. Staufer and Grimson (2000) employed event detection and classification for monitoring people activities (direction, coming and going out). Haritaoglu et al (2000) detected single and multiple people and monitored their activities in an outdoor environment. These researches on video processing for pedestrian, however, are not employed to gather pedestrian data in the microscopic level. Therefore, we have developed our own system to automate the pedestrian data collection for the microscopic level. The descriptions so far have been assuming that NTXY database has been gathered. This section describes how to obtain NTXY database from the video files by microscopic video data collection.

Images of pedestrians are taken by video camera in the field, on top of pedestrian facilities. A pedestrian trap, which is an imaginary rectangle, is marked in the middle of walkway as boundary of the system. Only pedestrians who pass the trap are considered. The images from the video are then converted into files in the laboratory using commercial software. The automation processes then begin with imageprocessing analysis. A video file can be seen as a collection of image sequence. Each image is called a slice or a frame. Fairhurst (1988) described an image as twodimensional function, where the value of the function $f(x, y)$ at spatial coordinate $(x, y)$ in the $x-y$ plane defines a measure of light intensity of brightness (or gray level) at that point. Each spatial coordinate is called a pixel, representing a cell on a matrix containing an intensity level, which are digitized from the original continuous image function. The target of the image processing is to detect the location of pedestrians for each image. To detect the location of pedestrians, the pixels that picture the pedestrians must be first detected. Since in reality, pedestrians may use any color of clothes and the environment is of different colors, to ease the detection of pedestrian pixels, the background view needs to be removed.

Because the image sequence comes from a static camera that is taken in a location with one focus, the background view of the image is almost at constant brightness. Only pedestrians and objects, which are moving, have changing gray levels. Based on
this phenomenon, the image can be separated into background view and moving objects. Background image is a frame where the pedestrian facility (i.e. walkway) does not have any pedestrian. Background subtraction is one of the best tools for segmenting motion images from the static background. The algorithm is simple and fast compared to other methods. The background image was traditionally initialized by manual searching. Automatic background image may be developed automatically from the video images when there are no objects, as suggested by Matsuyama (1999). Then, object images are binarized into black and white pictures. For every frame, two pictures are created. One is the original color image and the second is the binarized image. Standard binary morphological operations of closing and opening are performed to reduce the noise and increase the unity of connected components of the objects. The morphological operation has been discussed in many digital imageprocessing textbooks (e.g. Gonzalez and Woods (1993)).

After the moving objects are separated from the background, the pixels that contain the picture of pedestrians and other moving objects are detected in the binarized image. The image is scanned from the top left to bottom right. If a black pixel is found, the location of the pixel is stored and the neighboring pixels are searched. If any of the eight directions of the neighbor pixels contains a black pixel, the black pixel is called connected. All the connected black pixels may produce a region that represents a moving object. After objects in the binarized image are detected, all pixels in the corresponding location of the original color image are captured. A bounding box is drawn to mark a detected object. Based on the color and binarized pixels, object features are calculated. Statistical descriptors as well as binarized and color descriptors are calculated. The statistical descriptors are determined based on the histogram of the pixels such as mean, variance, relative smoothness, skewness, kurtosis, energy, and entropy. The binarized descriptors are calculated based on binarized image such as area, and perimeter, ratio of box height and width. Area of an object is the number of black pixels in the region bounded by the box. Coordinate of the moving object is calculated based on the center of gravity. Each black mask of binarized image has a corresponding pixel in the color image that can be measured as color object descriptors. The descriptors of each basic color, Red Green and Blue are measured and the averages of the three components represent the color descriptors. Mean color, color standard deviation and center of gravity of color is quantified as color descriptors.

If the area of an object is too small for a pedestrian it is considered as a noise and deleted from the data. Performing the above algorithm of background subtraction, object detection and object descriptors toward all frames of the video produce a database, called a descriptor database. Each row in the descriptor database represents a moving object in a frame while the columns represent object descriptors. A unique slice-object number is assigned to each object in the descriptor database. This sliceobject number does not represent the real pedestrian number since it is only an ordered number for each frame. Each image of the pedestrian in each frame is represented by one point, which is the centroid of its area. Starting from the first frame, each point is numbered by a unique pedestrian-number. A simple tracking
procedure is done to follow the movement-path coordinates of each pedestrian for every frame.

The objective of the tracking algorithm is to match the objects between frames by giving a pedestrian number to each slice-object number in each frame so that if they represent the same object, they will have the same object number. Two points in two consecutive frames are matched if and only if the two points represent one pedestrian. Each pedestrian is traced frame by frame from the time he/she shows up in the image until he/she goes out of the image. To match the corresponding objects from one frame to another, matching is executed. Matching is based on proximity and similarity. The proximity depends on the speed of the object and distance of one object to another, while the similarity relies on the object's features. Matching is done by comparing the features of a base object with all candidate objects in the searching slice. A valid candidate object can not be chosen as a matched object if it has been chosen previously unless it has the same object number as the base object. Since an object is assumed to be moving at a certain maximum speed limit, a speed threshold is set to reduce the computation of similarity values. The speed threshold depends on the frame rate, camera focus, and the depth of object from the camera and the maximum speed of the object. The higher similarity index of a candidate object, the higher the chance that the candidates object is the matched object.

To distinguish pedestrians from other moving objects, the recognition procedure is applied. The recognition is performed based on the assumption that other moving objects are just noises and small movement objects' (e.g. papers decorations, leaves of the trees) movement are not continuous. Checking the continuity of the motion of each object distinguish pedestrians from the other objects. Deleting all non-pedestrian rows and renumbering the pedestrian numbers provide the right database. Following the recognition, calibration of image coordinates to the real world coordinates is performed using linear regression. The calibration is achieved by taking several points in the field and its corresponding points in the images. A simple affine transformation to convert image coordinates $\left(X_{i}, Y_{i}\right)$ to real world coordinates ( $X, Y$ ) was found using linear regression:

$$
\begin{align*}
\mathrm{X} & =\mathrm{u}+\mathrm{v} \cdot \mathrm{X}_{\mathrm{i}}+\mathrm{w} \cdot \mathrm{Y}_{\mathrm{i}}  \tag{13}\\
\mathrm{Y} & =\mathrm{x}+\mathrm{y} \cdot \mathrm{X}_{\mathrm{i}}+\mathrm{z} \cdot \mathrm{Y}_{\mathrm{i}}
\end{align*}
$$

As an example of the experiment, for video data that was taken from above 12-15 meters from the ground, the conversion model was obtained using 151 data:

$$
\mathrm{X}=\underset{(44.3)}{66.45+1.23 \mathrm{X}_{\mathrm{i}}-0.99 \mathrm{Y}_{\mathrm{i}}} \quad \mathrm{R}^{2}=0.999
$$

and

$$
\mathrm{Y}=\underset{(151.9)}{250.87}+\underset{(17.5)}{0.067 \mathrm{X}_{\mathrm{i}}}+\underset{(344.3)}{1.29 \mathrm{Y}_{\mathrm{i}}} \quad \mathrm{R}^{2}=0.998
$$

The $t$-statistic is given in the parentheses. The maximum error was +17 cm for X and -21 cm for Y at the edge of the image. The errors were almost zero at the center of the image. Placing the pedestrian trap in the center of the image is one strategy to reduce the error. Though the video was gathered at 30 Hz , the data was taken every 0.5 second $(2 \mathrm{~Hz})$ to keep the accuracy. More slices in every second (higher frequency) do not produce much movement of pedestrian due to the size of the picture. Smaller frequency will produce a rough behavior of pedestrians movement. A NTXY database, which consists of fields of pedestrian number, coordinate location, and time, is finally produced from these data collection procedures.

## RESULTS AND DISCUSSIONS

This section presents some results of the video data collection and the flow performances. Although the procedures to calculate and graph the pedestrian movement variables and flow performance from the video image file are done automatically, each step of the procedure can also be executed separately. The separate execution is useful for inspection purposes.

The result of video processing was satisfactory for low density pedestrian since it is able to detect and track the movement of pedestrians who walk separately. It can detect the new coming and going out of pedestrians without occlusion. When projection of a 3D object toward a plane may produce a view of overlapping objects, an occlusion scene happens. Though the actual objects do not merge with each other, the projection on the camera plane may display a merging object view. Occlusion is a phenomenon wherein two or more objects may move too close to each other and is detected as one object. Later these objects may separate again as an individual object. Pedestrians who walk too close to each other are falsely detected as one pedestrian. Figure 4 shows the result of video processing. The top left picture is the original frame; bottom left is the background view. The top right is the result of background subtraction The results of tracked pedestrians are shown in the bottom right. A pedestrian detected is marked with a box and a unique pedestrian number.

Once the data is collected, NTXY database is produced. Based on the NTXY database, individual and average flow performance and traffic flow variables can be calculated. Figure 5 shows the movement trajectory for three pedestrians based on a NTXY database. In the top left figure, each line represents movement of each pedestrian who moves from the south to north direction. The Y and X trajectory is drawn in the top right and bottom left. Looking at the Y trajectory, the two pedestrians are close to each other in terms of the Y direction but they are not close in X direction. This characteristic reminds us that pedestrians have more movement dimension than cars. The speed profile is shown in the bottom right. Comparing the speed profile and the movement trajectory, it reveals that the behavior of a not so smooth movement of two pedestrians in the movement trajectory can also be seen in the speed profile. The fluctuation in the speed profile represents the ragged behavior in the movement trajectory.


Figure 4. Experimental video data collection on the top of a sidewalk. Source:
Authors' program


Figure 5. Movement Trajectory for several pedestrians. Source: Authors' program

Figure 6 shows an example of the individual flow performance that was calculated based on the video data collection. The unit distance is in cm and the time unit is in seconds. The three indexes shown in the Figure 6 can be referred in Table 1. Number of observations is the number of points gathered for this pedestrian. The distance between two consecutive points in time represents the instantaneous speed. Acceleration is the difference of speed over time while jerk is the difference of acceleration over time.

The mean instantaneous speed ( $98.67 \mathrm{~cm} /$ second) is almost similar to low-density walking speed for shopping $3 \mathrm{ft} / \mathrm{second}$ as reported by Older (1968). Small acceleration and jerk is recorded by this system. Pace uniformity index measures the length of each pace compared to an ideal straight line. The number 0.94 describes that the movement trajectory is almost a straight line. The small numbers of uncomfortability index and delay supports this value of pace uniformity index. Angle of direction is measured by taking the tangent of unit direction in equation (8). The direction is 37 degrees from the X direction moving Northeast.

To be able to compare the number of individual flow performance with the movement of the pedestrian, the movement trajectory of one pedestrian is drawn in Figure 7. Each point in the line represents the movement of pedestrian at each time, viewed from the top of pedestrian facilities. The X and Y trajectory that represent the spacetime diagram from the same data of this pedestrian. A line up to the right in Y trajectory represent a pedestrian who move to the north direction, while each line down to the right depict the pedestrian who walk to the south. In X trajectory, a line up to the right represents a pedestrian that move from west to east direction. It revealed that the X trajectory is almost a straight line.


Figure 6. Flow Performance Results. Source: Authors' program


Figure 7. Speed, acceleration and jerk profiles and trajectories of a pedestrian. Source: Authors' program

Since the movement of pedestrians is not in an ideal straight line, acceleration and jerk happen. Figure 7 shows the profile for instantaneous speed, acceleration and jerk. These profiles can be compared with the movement trajectory, X and Y trajectory. The speed is reduced when the movement is making a curve in both X and Y directions. When the speed is reduced, the acceleration is negative and the jerk is the highest. When the pedestrian walk with a stable movement, the acceleration and jerk is almost constant and oscillates. The oscillations of acceleration and jerk may be due to the pace or step of pedestrian.

Figure 8 shows an example of the result for traffic flow variables as explained in Table 2. Spacing is the minimum distance between pedestrian at each time slice. The time headway is approximately obtained by the spacing divided by the instantaneous speed. Again, the distance unit is in cm and time unit is in second.

Above examples reveal that the measurement of movement behavior of pedestrian has been advanced into measurement of pedestrian flow performances, including instantaneous speed, acceleration and jerk profile. Headway and spacing is also gathered along with the macroscopic pedestrian traffic-flow variables. It was confirmed that the procedures described have significant potential to automate measurement of both microscopic and macroscopic pedestrian flow variables and performances.


Figure 8. Traffic Flow Variables. Source: Authors' program

## Conclusions

This paper has suggested a paradigm to improve the quality of pedestrian movement by considering their interactions in microscopic level. Using this approach, the design of pedestrian facilities is not merely a space allocation but it can also utilize other forms of flow controls in space, time and direction.

Digitalization of video data collection into NTXY database has been proposed to convert video into numbers. Following this conversion, the rest of the process can be done by a computer that reduces the processing cost and improves speed and accuracy. The same result is always gathered for the same data. Unlike macroscopic video counting device that is useful only to gather macroscopic variables, NTXY database can be used to obtain both microscopic and macroscopic flow performances as well as other movement behavior of pedestrians. Both microscopic pedestrian simulation model and microscopic video data collection can produce the NTXY database.

Pedestrian flow performances measure the interaction of pedestrians whether between each other or with the environment directly or indirectly. Flow performance is a broader concept than traffic flow variables because traffic flow variables are also part
of the flow performances. The data reduction of NTXY database into well-established traffic flow variables and some prominent flow performance was formulated. Huge data from the video is reduced into information that can be readily understood and interpreted. Individual and average flow performance and traffic flow variables are calculated and the individual trajectory can be graphed.

Measurements of microscopic flow performance in the real world need to be elaborated in parallel with the automation of data collection. The automation system of microscopic pedestrian data collection was explained. The automation converts video files into NTXY database. The errors from the automation were discussed. The result of video processing was only satisfactory for detecting the movement of pedestrians who walk alone. Measurement of movement behavior of pedestrian has been advanced into measurement of pedestrian flow performances, including instantaneous speed, acceleration and jerk profile. Headway and spacing is also gathered along with the macroscopic pedestrian traffic-flow variables. It was confirmed that the procedures described have significant potential to automate measurement of both microscopic and macroscopic pedestrian flow variables and performances.

Many kinds of pedestrian flow performances may be developed and their relationship with pedestrian behavior and improvement of the microscopic video data collection is recommended for further research work.

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