Utilizing Video Footage for the Analysis of Pedestrian Behavior

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Abstract

This paper presents an analysis of pedestrian traffic performance from an empirical study. Video footage from a university building corridor was used to quantify pedestrian behavior for inclusion in a pedestrian simulation model. A coordinate conversion technique that maps images in the footage onto a real-world coordinate system was used for data collection. Pedestrian characteristics such as average speed, density, and flow rate were measured to examine traffic performance. The impact of gender and group size on pedestrian speed, as well as trajectory change and spacing, were tested and reviewed to verify the influence of environment on pedestrian behavior.

Keywords
Pedestrian behavior, Image analysis, Traffic performance

1. Introduction
Pedestrian behavior with traffic flows has only been given limited attention in recent research. One of the reasons is that tools to analyze pedestrian behavior and pedestrian traffic flows are scarce. Interest in the field is growing due to the integral nature of walking as a part of the transportation chain. There is a current need to more accurately depict pedestrian movements and behavior to improve transportation facility design. This research presents a means of obtaining such data, and seeks to incorporate behavioral studies and data into a simulation model [1].

Behavioral studies found in the literature define a number of strategies used by pedestrians as they navigate through a crowd. Related to collision avoidance, pedestrians tend to either change their trajectory or change their speed. They also have a number of strategies that are employed when passing other pedestrians. These collision avoidance patterns are impacted by the individual behavior, as well as the density of the crowd [2]. Pedestrians demonstrate a territorial effect in that they tend to keep a minimum distance from others in the crowd. They also exhibit a preferred minimum distance when passing obstacles. This preferred distance, or territory, is smaller as the pedestrian hurries and is also reduced with growing crowd density [3].

Data and statistics from an empirical pedestrian study are useful when they can be applied to model behavior for a general population. With an appropriate pedestrian model, we can predict and analyze the behaviors of pedestrian. However, it is hard to get numerical solutions from the model when it is complicated itself or needs to process huge data sets at a time. There are some common approaches to pedestrian simulation including cellular automata, social force, magnetic force, and queueing network model. Cellular automata consist of an array of grid cells that represent the pedestrian environment [4]. Pedestrian agents, that each occupies a single cell at any given time, accomplish movement using updated localized neighborhood rules. In a social force model, pedestrians are motivated to move in response to attractive and repulsive forces exerted by their surroundings [3]. Similarly, a magnetic force model is composed of positive poles and negative poles that represent obstructions and goals, respectively [5]. In queueing network models, nodes represent the current locations that are linked to define possible routes to navigate [6].

2. Image Analysis

2.1 Video Footage collection Methods
The site chosen for study was an academic building on the campus of Mississippi State University. The video footage was taken from a surveillance camera, which is facilitatated on the ceiling of a first floor corridor, about 4 m
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(12 ft) above the floor. The video footage analyzed was collected from archived footage of April 30, 2007. The selected site was 3 m (10 ft) * 22 m (71 ft) with an area of 66 m² (710 ft²). The footage displayed 20 minutes of behavior during a period between classes. Location and attribute data (gender, group size, etc.) were collected on a sample of 68 pedestrians. The location data was subsequently used to calculate speed, trajectory, and distance from obstructions.

2.2 Image and Coordinate Conversion

The footage was exported onto a hard drive as an .avi file and converted to a stacked sequence of images at 2 frames per second using VirtualDub, an open-source image processing utility [7]. A total of 2,280 jpeg image stacks were created. Manual pedestrian tracking was performed for each video frame. To reduce experimenter error and complexity, each frame was trimmed to accentuate the region of interest (ROI) as depicted in Figure 1. It displays both the region of interest (solid lines) and the point of analysis (dotted line). Pedestrians who passed through the ROI were included in the study.

![Figure 1: Region of interest and point of analysis designation](image)

The image coordinates that represent pedestrians’ current positions in each frame were acquired using ImageJ [8], an image processing and analysis tool, assuming that the middle point of a pedestrian’s feet represents his/her current location \((x_{image}, y_{image})\) in each frame as showed in Figure 1. The second assumption is that the coordinate for the overlapped pedestrian by the front or taller people was forecasted with his/her previous trajectory coordinates taking moving averages. Each pedestrian was assigned a unique ID. The pedestrian’s image coordinates were recorded in a matrix format while tracking pedestrian coordinates frame by frame. This sequence of work continued from the time the pedestrian entered the footage until they exited. Table 1 shows a sample of the data collected, including pedestrian ID, frame numbers, and image coordinates.

<table>
<thead>
<tr>
<th>Ped ID</th>
<th>Frame# (0.5sec/fr)</th>
<th>X (image)</th>
<th>Y (image)</th>
<th>Ped ID</th>
<th>Frame# (0.5sec/fr)</th>
<th>X (image)</th>
<th>Y (image)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>168</td>
<td>175</td>
<td>131</td>
<td>7</td>
<td>230</td>
<td>210</td>
<td>73</td>
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<td></td>
<td>169</td>
<td>174</td>
<td>140</td>
<td></td>
<td>231</td>
<td>217</td>
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<td>152</td>
<td></td>
<td>232</td>
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<td></td>
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<td>162</td>
<td>159</td>
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<td>233</td>
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<td>67</td>
</tr>
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<td></td>
<td>172</td>
<td>156</td>
<td>172</td>
<td>8</td>
<td>384</td>
<td>247</td>
<td>76</td>
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<td></td>
<td>385</td>
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<td></td>
<td>174</td>
<td>144</td>
<td>208</td>
<td></td>
<td>386</td>
<td>229</td>
<td>73</td>
</tr>
</tbody>
</table>

Due to the camera angle and lens distraction, coordinate conversion is required to analyze pedestrian traffic performance and related behaviors because the acquired image does not represent the rectangular corridor area in
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real. Therefore, the real floor plan coordinates \((x_{\text{real}}, y_{\text{real}})\) are estimated from the image coordinates \((x_{\text{image}}, y_{\text{image}})\) with the trimmed data set from ROI. The calibration process starts with recording current image coordinate matrix, followed by taking the affine transformation for both length \((x_{\text{real}})\) and width \((y_{\text{real}})\) with \((x_{\text{image}}, y_{\text{image}})\) and \(\beta\)'s [9].

Next, multiple linear regression, using stepwise method, is taken to find the estimated values of parameters \((\hat{\beta}\)'s).

\[
\begin{align*}
\hat{x}_{\text{real}} &= \hat{\beta}_0 + \hat{\beta}_1 x_{\text{image}} + \hat{\beta}_2 y_{\text{image}} \\
\hat{y}_{\text{real}} &= \hat{\beta}_0 + \hat{\beta}_1 y_{\text{image}} + \hat{\beta}_2 y_{\text{image}}
\end{align*}
\]

These equations have been applied to estimate parameters and predict real coordinates using 50 randomly sampled coordinate data sets, which were directly measured from the real floor plan coordinates.

3. Data Analysis

In this section, we provide a description of pedestrian traffic performance and related behaviors based on the converted data set from the prediction equations calculated above. To begin, instantaneous pedestrian travel speed needs to be calculated in order to analyze microscopic pedestrian behavior. For any observation time \(n\), the distance between frame \(n\) and \(n+1\), for any pedestrian navigation, was calculated in Euclidean space.

\[
\text{Distance} = \sqrt{(x_{n+1} - x_n)^2 + (y_{n+1} - y_n)^2}
\]

This sequence of work continued from the birth of a pedestrian to their death within the specified ROI tracing pedestrian trajectory frame by frame. Once we finished tracking the first pedestrian’s trajectory in ROI, we moved our focus onto the second pedestrian, and continue tracking until there are no pedestrians left in the last frame. Instantaneous pedestrian speed was obtained using the distance calculated in Equation (2) and the frame rate (two frames per second). We assumed that the initial speed of each pedestrian is zero, and we did not take it into account when calculating average instantaneous speed.

\[
\text{Instantaneous speed} = \text{distance} / (0.5\text{sec/fr})
\]

The next fundamental characteristics of pedestrian traffic flow are flow rate and density. These were chosen as they have a high impact on the efficiency and utilization of pedestrian facility layout as well as the design guidelines and policies for pedestrian facilities. Flow rate is defined as the number of pedestrians passing a point of analysis (as depicted in Figure 1) in a unit of time, that is, pedestrians per width of walkway per time unit [10].

\[
\text{Flow rate} = \frac{\text{# pedestrians}}{(\text{observation time}) \times (\text{walkway width})}
\]

Pedestrian density is the number of pedestrians within the given unit of area (ped/m^2). Area module, the reciprocal of pedestrian density (m^2/ped), is used in this study because it is easier to manage and relates to facility design. As stated, instantaneous average speed was recorded tracking all the pedestrians in each frame, and instantaneous area module was calculated for each frame by dividing the area of ROI by the number of pedestrians in each frame. Flow rate was also calculated and is equivalent to the product of instantaneous average speed and density in each frame.

When pedestrians are faced with an imminent collision, they often make a decision to pass another pedestrian changing their speed or trajectory so as to have individual preference of mutual distance. Behavioral studies have shown that pedestrians change their speed and trajectory with sidestepping and adjustment [4] [11] to keep their current direction as they move toward their goal destination maintaining their preferred minimum distance from other pedestrians and obstacles. Each pedestrian’s minimum distance from obstructions in each frame was measured to evaluate how much distance pedestrians keep from obstructions as they navigate. We regarded trajectory changes of 45 degree or less as side steps, which means no trajectory changes have been made, when measuring changes in trajectory. The relationship between speed and the number of trajectory changes as well as speed and distance from obstructions were tested and depicted in the following section.

4. Results and Discussion

The least squares prediction equations for coordinate conversion were obtained in metric as follows:
The coefficients of determination were 0.907 and 0.891 respectively. The average instantaneous pedestrian speeds by gender and group size are presented in Table 2. The overall average speed was 0.99 m/s (3.25 ft/s). This value is lower than the average speed for young pedestrians (1.45 m/s) reported by [12]. The difference is most likely due to the fact that the pedestrians in the study tended spend a lot of time stationary while talking to neighbors, as well as a travel agenda with little time pressure.

### Table 2: Speed by pedestrian type

<table>
<thead>
<tr>
<th>Gender</th>
<th>Group Size</th>
<th>Sample Size</th>
<th>Speed (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
<td>10</td>
<td>0.866</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9</td>
<td>0.492</td>
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<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>0.633</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>13</td>
<td>0.675</td>
</tr>
<tr>
<td>Male</td>
<td>1</td>
<td>48</td>
<td>1.191</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18</td>
<td>0.697</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7</td>
<td>0.305</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>0.091</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>55</td>
<td>1.065</td>
</tr>
<tr>
<td>All</td>
<td>1</td>
<td>57</td>
<td>1.143</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>26</td>
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<td></td>
<td>3</td>
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<td>0.091</td>
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<td>Total</td>
<td>Overall</td>
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<tr>
<td></td>
<td></td>
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<td>0.699</td>
</tr>
</tbody>
</table>

The flow rate observed in the video footage was 2.38 ped/min/m and the area module was 38.49 (m²/ped). These metrics can be used in evaluating the level of service of a pedestrian facility with maximizing flow rate being an objective. Unlike the general case, the average speed of men was greater than that of women, and they are significantly different from each other with the p-value of 0.002.

The comparison of average speeds by group size was taken into account. Figure 2 shows that a single pedestrian walks faster than others in group (p-value<0.001), and a group of two walks faster than a group of four (p-value<0.001). However there was no significant difference in average speed between group of two and three as well as group of three and four (p-value<0.001). Pedestrians walking alone composed 59.4% of the sample studied.

It has been found that the number of changes in trajectory had a week linear relationship with pedestrian speed ($r^2=0.23$, Speed = 1.284 - 0.03937×TrajectoryChange) as described in Figure 3. As pedestrians made less trajectory changes, their speed was faster than those who made greater ones. The mean number of trajectory change in this study was nine, and there was a significant difference in average speed between less than average trajectory change group (1.2 m/s) and greater than group (0.48 m/s) with the p-value of 0.001. The slow walkers on average in the study showed meandering or stationary movements while talking to their neighbors or waiting for an elevator whether they made frequent trajectory changes or not. After trimming non-homogeneous data, an improved linear association was found.
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with an $r^2=0.6$ (Speed = 1.867 - 0.1147×TrajectoryChange). In addition, there was a significant difference between pedestrians who made their trajectory change of less than 45 degree and greater than 45 degree (p-value<0.001) with regard to average speed. The average speed of the former group was 1.30 m/s, and the latter was 0.66 m/s. Totally, 75% of the trajectory changes were 45 degree or less throughout the frames. Based on the assumption in previous section, it can be said that the majority of people took side steps while changing their speed to avoid collision and maintain their current direction.

![Figure 3: Speed as a function of trajectory change](image1)

![Figure 4: Speed as a function of spacing](image2)

Figure 4 displays the pedestrian speed as a function of distance from obstructions (other pedestrians and obstacles) representing a linear relationship between them with $r^2=0.25$. It can be said that pedestrians who have greater minimum distance from obstructions walk faster than those who have smaller one (Speed = 0.4731 + 0.1981×Spacing). That is because they tend to have better situation awareness and a high amount of information to ensure their desired speed and collision avoidance taking appropriate actions in advance.

Based on the results from empirical studies, a behavioral model can be built, and a simulation model is to be validated as well. There are a number of objects to consider when developing or running a pedestrian simulator. For instance, objects in the system may include pedestrian characteristics, behavior responses, obstructions, building layouts, and personal agendas. Many of them can be derived from empirical studies such as spatial-temporal data (location, speed/acceleration distribution, agent spawning frequency by time), behavioral rule set by condition or probability (speed/trajectory change, sidle stepping, negotiating rule for collision avoidance, spacing), or demographic data (mobility by age/gender/physical condition, body ellipse).

5. Conclusions and Future Work

As this paper shows, a method of utilizing video footage to analyze pedestrian behavior was taken into consideration. A coordinate conversion technique was presented to represent image coordinates as real-world coordinates by means of multiple linear regression analysis. The obtained set of coordinate information from the image frames has been used to calculate the individual instantaneous walking speed, density, flow rate, trajectory change, and individual spacing. The average instantaneous speed was 0.99 m/s, and instantaneous acceleration was 0.06 m/s². The flow rate observed in the video footage was 2.38 ped/min/m and the area module was 38.49 (m²/ped). These metrics will be used in evaluating the level of service of a pedestrian facility. The level of service of this corridor was level A (based on flow rate) and E (based on area module) according to its definition in the Highway Capacity Manual [13]. The main reason that this particular corridor was poorly rated in use of space can be interpreted as meager space allocation for each pedestrian. As a whole, it can be said that this corridor is wide enough for pedestrian navigation under usual circumstances. However, the utilization was poor at the time due to situational factors. Many pedestrians in the hallway were waiting to enter rooms, thereby decreasing utilization. A single pedestrian walks faster than others in groups of two or more. It was found that the average trajectory change was 39 degree, which means pedestrians prefer to change their speed rather than change their trajectory when they experience imminent collision or have obstructions near them. Both changes in trajectory and individual spacing affected pedestrian speed, and
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have linear relationships with speed. Developing a speed equation as a function of demographics may be useful as there were significant differences in average speed based on gender and age.

Additional behavioral studies and analyses are ongoing. To save the amount of time required to identify unique pedestrians, an automatic pedestrian tracking will be developed by using a robust object detection algorithm. There is a need to enhance the reliability of coordinate conversion so as to get better prediction equations. Additional behavioral studies are ongoing to obtain more accurate profiles for the speed and acceleration of each individual pedestrian, and crowd behaviors under high density. The additional studies will also create a more robust data set, increasing the quantity and quality of the data collected.

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References