A Study of Pedestrian Observation System with Ultrasonic Distance Sensor

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***Abstract*— A measurement of the pedestrian traffic becomes a key issue for supporting guidance of safety and for investigating a viewer's evaluation of an advertisement in a shopping district. In this paper, in order to measure the pedestrian traffic, we propose a new pedestrian observation system using ultrasonic distance sensors. From an experimental evaluation in a shopping street, we have confirmed that the proposed system accurately detects a trend of the pedestrian traffic. Moreover, we have concluded that the proposed system can estimate the congestion of the shopping street from the number of pedestrians derived from sensor data. Furthermore, we have confirmed that the proposed system can estimate the attention level of digital signage programs by using sensor data. The attention level can be utilized for improving the contents of the digital signage.**

***Keywords*— Sensor Network, Digital Signage, Ultrasonic Distance Sensor, Pedestrian Traffic Measurement**

I. Introduction

A pedestrian traffic measurement becomes a key issue for supporting human activities in various areas. For example, in shopping streets, if a manager of the shopping street can detect the congestion of the street by some means, it is useful for supporting guidance of safety, evacuation, etc.

On the other hand, a digital signage is spreading as a new advertising media instead of a paper advertisement, and an owner of an advertisement can easily change the contents of the digital signage by considering the viewer's evaluation of the advertisement. In these applications, the amount and the trend of the pedestrian traffic may be utilized as a measure of attention to the signage program. This is because the pedestrians change their moving directions or speeds when looking at the digital signage.

In order to measure the pedestrian traffic, a camera has been generally used. However, use of the camera has a problem in terms of privacy or cost. These problems also exist in a field of the shopping street, for which a camera is used to detect persons walking around the street or viewing the signage.

In order to solve these problems, we propose a new pedestrian observation system using low-cost ultrasonic distance sensors. Furthermore, the effectiveness of the proposed system is presented through an experiment in the shopping district.

II. Related Works and Objectives of Study

In a field of a measurement of the pedestrian traffic, the method of measuring pedestrians by using a camera has been proposed[1]. This method captures persons and tracks the number of pedestrians by analyzing recorded image data. However, this method is not suited for measurement in the nighttime, etc. Moreover, this method has some privacy concerns and may be difficult to be installed in some areas.

On the other hand, in order to measure the number of pedestrians directly, the method using 3D laser scanner has also been proposed[2]. This method detects pedestrians by measuring a distance based on round trip time of a laser pulse. However, the 3D laser scanner is very expensive and large, so the installation becomes difficult.

Considering these situations, we propose to use an ultrasonic distance sensor, which makes it possible to construct small and privacy free measurement environment. We also propose the method to detect velocities of pedestrians, by which we can estimate an attention level of digital signage contents.

III. Proposed System

A. Overview of the Proposed System

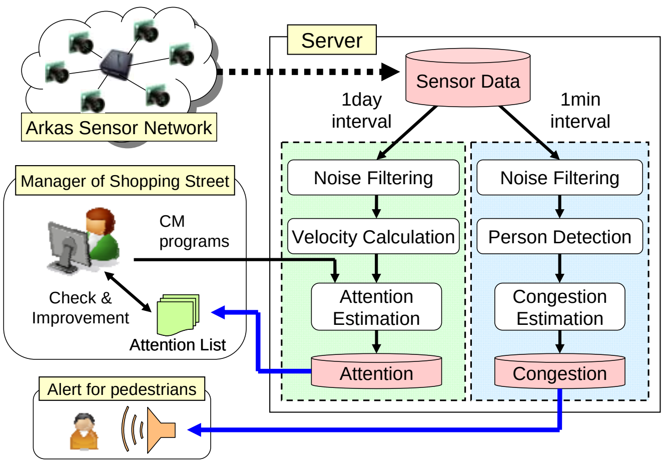


Figure 1. An overview of the proposed system.

Figure 1 shows an overview of the proposed pedestrian observation system. In this system, the server estimates two parameters, which are 1) the congestion of the street and 2) the attention of the digital signage, by analyzing a sensor data.

In this study, the congestion expresses an extent of the number of pedestrians of area where the system is installed. The attention expresses an extent that pedestrians are looking at the signage.

The output of this proposed system has twofold; 1) estimation of pedestrian population and 2) estimation of attention of digital signage contents.

Output 1), pedestrian population, can be used for analysis of crowd in that area. It may be further utilized for safety guidance in the shopping street etc. For example, an alert may be issued to pedestrians when a street becomes so congested or suddenly crowded. So, this congestion estimation should be done in real time, e.g., one minute interval.

Output 2), attention estimation can be used to evaluate contents of the digital signage, e.g., which contents have less attention from pedestrians than others. A manager may change those less-attention contents to others so that an effect of the digital signage can be improved. Therefore, the attention estimation can be processed daily.

B. Sensors for Detecting Pedestrians and their Walking Velocity

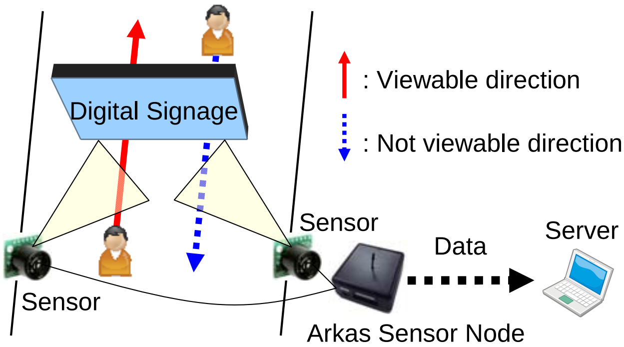
Figure 2 shows an idea to detect pedestrians and their walking velocity simultaneously. The sensor network is constructed by ultrasonic distance sensors and Arkas sensor nodes[3], and is installed near the digital signage.

In the proposed system, the sensor measures a distance to pedestrians. By analyzing a sensed data, the server detects a pedestrian's moving direction and velocity. From these velocities, the proposed system estimates whether pedestrians are looking at the digital signage or not, because pedestrians may reduce their speed when looking at the digital signage. As shown in Figure 2(a), this system targets the digital signage that is viewable from only one direction.

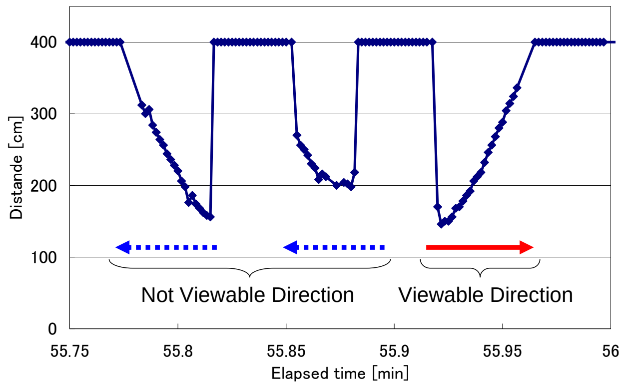
In the preceding study[4], the ultrasonic distance sensor was installed in the wall so that the ultrasonic wave crosses the street. However, this method has a problem that the system can detect a person from a sensor data but cannot detect a pedestrian's moving direction and a velocity. In order to solve this problem, in the proposed method, the sensor is installed in the wall by inclining the angle as shown in Figure 2(a).

Figure 2(b) shows an example of a sensor data. As shown in this figure, pedestrian's moving directions can be distinguished based on a difference of a tilt. Furthermore, velocities of pedestrians can be derived based on an extent of a tilt. For example, a tilt becomes a gentle slope when velocity of pedestrian is slow, and becomes a sharp slope when velocity of pedestrian is fast.

The ultrasonic distance sensor calculates a distance to objects from round trip time of the ultrasonic wave, and can detect a person within about 400 [cm]. Unlike the system using a camera, the ultrasonic distance sensor enables a measurement in the nighttime, and does not cause privacy issues.



(a) Inclined installation of sensors



(b) An example of sensor data

Figure 2. Methods of detecting moving direction and velocity.

C. Arkas Sensor Platform

A sensor platform will further facilitate this deployment by providing built-in data transfer between sensor nodes and a server. By connecting sensors to a sensor node, one can get data from a server. Figure 3 shows an overview of Arkas sensor platform. Two types of sensors are supported by Arkas at present, 1) ON/OFF or Open/Short data and 2) analog or voltage data. One does not need to manipulate or program the Arkas node. ON/OFF data of one bit and analog data of 10 bits sampling can be sent to the server with specified intervals.

The Arkas sensor node supports up to 7 analog interfaces and 16 ON/OFF interfaces. Furthermore, the sensor node is also quite small, 6.5cm width x 6.5cm length x 2.5cm height, and is designed for a few power consuming. It can be operated by a solar battery, but was powered by commercial electricity in the shopping street. Up to 16 Arkas sensor nodes can be connected to one server. The server is nothing but a software package built over Java, and can be operated over any platform (Windows, Linux, etc.). In the proposed system, we use a Linux server for evaluating experiments.

In the proposed system, the Arkas sensor node receives a distance data with analog interface from sensors with 100 [msec] intervals, and sends data to a server. The Arkas sensor node is server-client type sensor platform, and there is no need to install analyzing programs on the node. Accordingly, we can extend the number of sensor nodes easily.

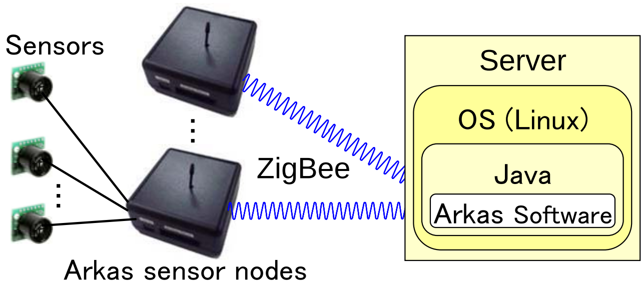


Figure 3. Overview of Arkas sensor platform.

IV. Detail Method of the Proposed System

A. *Method of Congestion Estimation*

In the first step of congestion estimation, the server performs a noise filtering to eliminate the noise. Figure 4 shows an example of the noise filtering. In this algorithm, the following data are considered as the noise.

- Distance data over 400 [cm].
- Distance changed largely for a few consecutive measurement instances.

Regarding the first item, the server modifies the data into 400 [cm]. Regarding the second item, we decided whether the data is a noise or not based on the average of data and the standard deviation. The server judges data satisfying the following condition as a noise, and eliminates that.

d_i : Sensor data [cm] at time i (100 [msec] intervals)

$$\mu_i = \frac{1}{2n+1}\sum_{j=i-n}^{i+n} d_j \tag{1}$$

$$\sigma_i = \sqrt{\frac{1}{2n+1}\sum_{j=i-n}^{i+n}\left(d_j - \mu_i\right)^2} \tag{2}$$

if ($d_i < \mu_i - \sigma_i$ or $d_i > \mu_i + \sigma_i$) **then** d_i is noise.

In the above condition, n (e.g., 1 to 5) will be decided taking account of noise filtering performance.

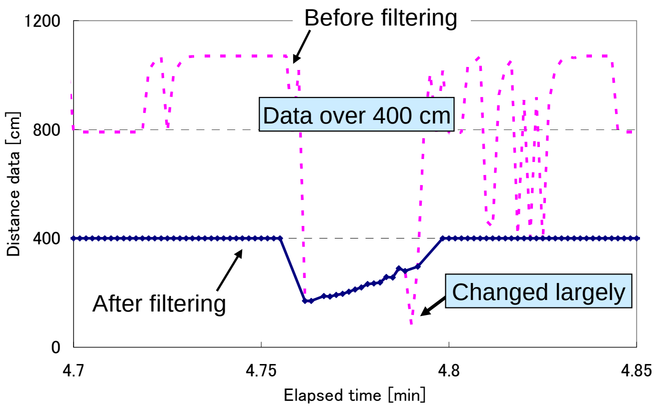


Figure 4. An example of noise filtering.

In the next step, in order to detect persons, the server extracts a part of a tilt from the filtered data as shown in Figure 2(b). Additionally, the server considers an extracted tilt to be one person.

In the final step, the server estimates the congestion based on the number of pedestrians for each one minute. In this algorithm, the congestion is divided into several levels based on a threshold of the number of pedestrians.

Above mentioned processes are performed with one minute interval, and the system may alert pedestrians based on the latest congestion.

B. *Method of Attention Estimation*

In the first step of attention estimation, in order to eliminate the noise, the server performs a noise filtering in the same way as the method of congestion estimation. After filtering the noise from a sensor data, the server also extracts a part of a tilt from the filtered data.

Figure 5 shows an example of the extraction for calculating velocities of pedestrians. In this algorithm, in order to accurately calculate the velocity, the server extracts a high linearity tilt based on correlation coefficient. The server performs a linearization for an extracted tilt, and derives a velocity according to the following equation.

C_{LE} : A coefficient of the linear expression

$$v_P[km/h] = C_{LE} \times 40.6 \text{ : Velocity of person} \tag{3}$$

In this algorithm, we confirmed that the constant for calculating the velocity was 40.6 from the result of experiment that was performed to investigate the relationship between coefficients of the linear expression and velocities. A sign of C_{LE} (plus or minus) indicates the pedestrian's moving direction.

In the final step, the server estimates an attention of individual digital signage program based on velocities of pedestrians. In this system, it is assumed that the digital signage program i.e., time table of signage contents, is available before estimating an attention of the signage. Moreover, in this algorithm, the attention is divided into several levels based on a threshold of a velocity.

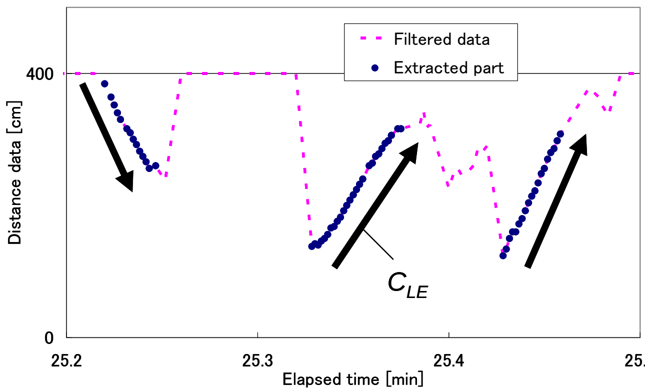


Figure 5. An example of extraction.

After analyzing sensor data with the above algorithm, the server outputs an attention list of digital signage programs for an owner of the signage with 1 day interval.

V. Evaluation Experiment and Results

A. Experimental Setup in a Shopping District

In order to investigate the practicability and performance of the proposed system, we performed an experiment in the shopping district in Kitakyushu-city, Fukuoka, Japan for four days. Figure 6 shows an experimental environment of this experiment. As a feature of the digital signage in this shopping district, the digital signage is hung at a height of about 5 [m] on the center of the street, and only pedestrians who walk from north to south can see the contents of the digital signage. As shown in Figure 6, in this experiment, two sensors are installed on both sides of the street whose width is 5.5 [m]. Moreover, we counted the number of pedestrians manually, as a reference for comparison with a sensor data. Audiences of the digital signage were also counted by checking pedestrian's eyes, as a reference for the attention estimation.

Table 1 shows an example of digital signage programs. In this shopping district, digital signage program for an hour is configured as one cycle, and length of the individual content is typically about 30 sec (minimum length is 15 sec, and maximum length is about 3 min).

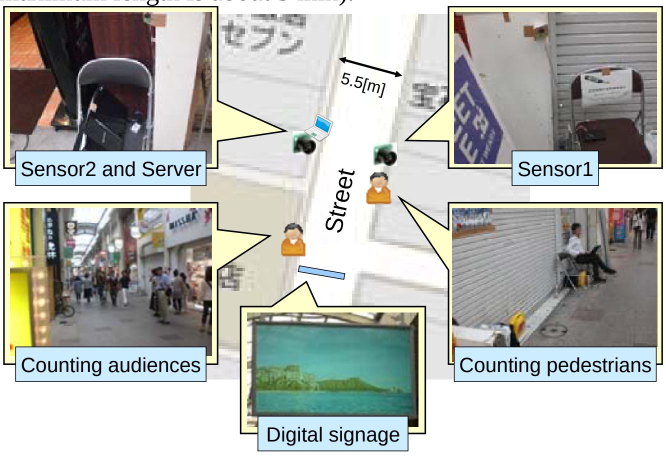


Figure 6. Experimental environment.

TABLE 1. An Example of Digital Signage Programs.

From	To	Contents
11:00:00	11:00:30	Cafe & Bar
11:00:30	11:02:00	Mobile phone shop
⋮		
11:58:00	12:00:00	Event information

B. Results of Pedestrian Detection

Figure 7 shows a transition of the number of pedestrians for four days. Correlation coefficient, between the number of pedestrians counted manually and that detected by sensor data, is 0.95. Therefore, the proposed system using the ultrasonic distance sensor can satisfactory estimate a trend of the pedestrian traffic with high accuracy.

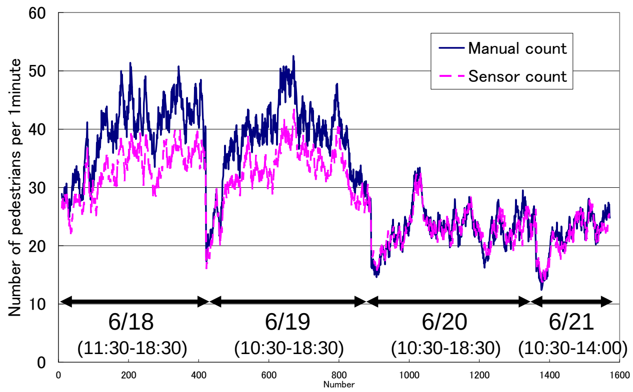


Figure 7. The number of pedestrians for four days.

C. Result of Congestion Estimation

In this evaluation, the congestion is divided into three levels based on the number of pedestrians for each one minute. The threshold to divide the congestion level is decided from the average of the number of pedestrians and the standard deviation of that. We set a different threshold between the weekday and the weekend, because the average number of pedestrians is typically different between them. In this system, we attempt to detect the congestion level "3" of the shopping street in particular, because the situation of the level "3" means that the street becomes too crowded, and is very danger for pedestrians of the shopping street. Therefore, we set the following value as the threshold for dividing the congestion level, so that the server can properly detect the congestion of this shopping street.

$$C_{TL} = \mu \quad (4)$$

: Threshold between the level "1" and the level "2"

$$C_{TH} = \mu + 1.5 \times \sigma \quad (5)$$

: Threshold between the level "2" and the level "3"

where

μ : The average of the number of pedestrians

σ : The standard deviation of the number of pedestrians

Table 2 shows a threshold of the number of pedestrians in this shopping street, and Figure 8 shows an example of the threshold of the weekend. Moreover, these thresholds should be implemented depending on the installation environment of the system. In case of this shopping district, the server may alert pedestrians in the shopping street by setting thresholds of the number of pedestrians as shown in Table 2.

TABLE 2. A Threshold of the Number of Pedestrians.

	Number of persons per 1 minute	
	The weekday	The weekend
Threshold between level 1 and level 2	22.9	33.1
Threshold between level 2 and level 3	27.3	38.9

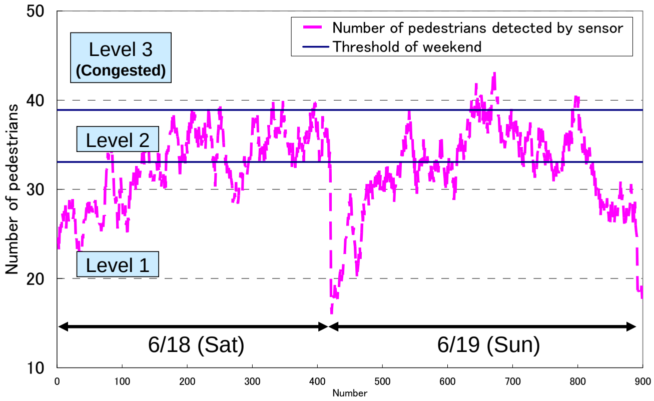


Figure 8. An example of congestion threshold of the weekend.

D. Result of Attention Estimation

Figure 9 shows a probability density of velocities of pedestrians in each direction. Average velocity of pedestrians moving in viewable direction was 3.35 [km/h], and that of pedestrians moving in non-viewable direction was 3.69 [km/h]. This result indicates that pedestrians reduce their speed when looking at the digital signage.

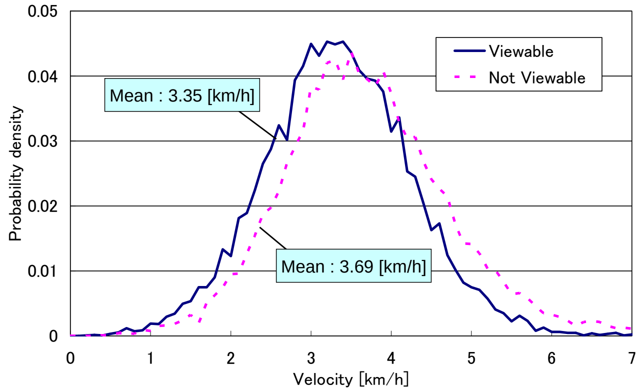


Figure 9. A probability density of velocities in each direction.

In this experiment, we manually counted the number of audiences of the digital signage as a reference. According to the results, we divided digital signage programs into two groups based on a value of an audience rate. Our purpose of attention estimation is to identify programs which do not obtain pedestrians attention. Therefore, 1 [%] is set as a threshold to distinguish group 1 (no attention) and group 2 (reasonable attention).

Table 3 shows an average velocity derived from sensor data for these two groups. The result indicates that the average velocity of the group 1 is faster than that of group 2. We conducted a t-test to clarify a significant difference between velocity of group 1 and that of group 2. P-value is the result of a t-test, and indicates whether there is a significant difference or not. From Table 3, a significant difference was confirmed on the average velocity between group 1 and group 2 at significance level of 1 [%]. Therefore, it is possible to estimate an attention of the digital signage into group 1 or group 2 using pedestrian's velocities.

TABLE 3. RELATIONSHIP BETWEEN VELOCITY AND AN AUDIENCE RATE

Group	Audience rate (manually decided)	V [km/h]	P-value to group 1 (t-test)	Number of programs
1	0% - 1%	3.47	-	10
2	1% - 50%	3.35	0.007	38

As shown in Table 3, the number of signage programs of group 1 is 10, and that of group 2 is 38. Here, we exclude three signage programs whose length is too short and whose audience rate is too high as an outlier.

Next, we attempt to divide an attention of each signage program into two levels based on velocities of pedestrians who walk under the digital signage during the program is displayed.

Attention level "L" expresses that pedestrians does not pay attention to the signage programs, and corresponds to group 1 in Table 3. Attention level "H" expresses that pedestrians pay attention to the signage programs, and corresponds to group 2 in Table 3. The server estimates an attention of the signage program is level "L" when the average velocity of the signage program is faster than a threshold of velocity.

In order to accurately divide an attention into two levels, we need to know a threshold of velocity so as to maximize the estimation accuracy. We investigated accuracy of the attention by changing a threshold of velocity.

Figure 10 shows a relationship between estimation accuracy and a threshold of velocity. The accuracy is an average probability at which the attention level of the signage program is correctly decided based on the velocity of pedestrians, and is calculated from the following equations.

$$P = \frac{1}{n}\sum_{i=1}^{n} M_i \quad \text{: The accuracy of the attention} \qquad (6)$$

where

if $(G_i == A_i)$ **then** $M_i = 1$ **else** $M_i = 0$

G_i : Group of signage program at number i (1 or 2)

A_i : Attention of signage program at number i (1 or 2)

In the above equations, $A_i = 1$ corresponds to attention level "L", and $A_i = 2$ corresponds to attention level "H".

As mentioned in Table 3, the number of signage programs in group 2 (i.e. 38) is much larger than that in group 1 (i.e. 10). Therefore, for calculating the accuracy correctly, we randomly select 10 programs from group 2 in each evaluation. We conducted 1,500 evaluations, and treated the average as accuracy of attention.

In Figure 10, if a threshold of velocity is too small, the accuracy becomes 50 [%] because all signage programs are judged as attention level "L". Similarly, if a threshold of velocity is too large, the accuracy also becomes 50 [%] because all signage programs are judged as attention level "H".

As shown in Figure 10, accuracy becomes the maximum value of 82.2 [%] when the threshold of velocity is 3.42 [km/h]. Therefore, we concluded that the threshold of velocity be set to 3.42 [km/h] in this shopping district.

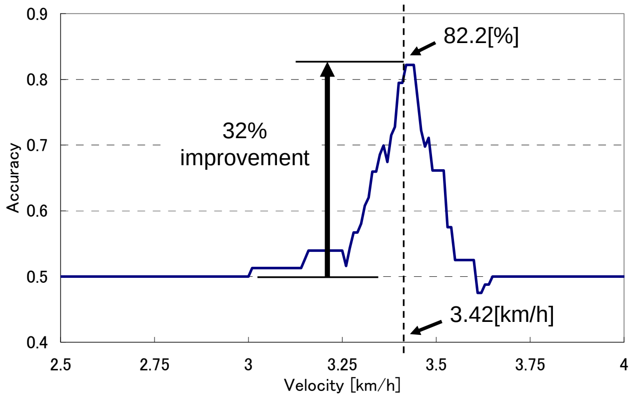


Figure 10. Threshold to distinguish group 1 and group 2.

VI. CONCLUSIONS

In this study, we have proposed a new pedestrian observation system using ultrasonic distance sensors. From an experimental evaluation of the proposed system conducted in the shopping street, we have clarified that correlation coefficient, between the number of pedestrians counted manually and that detected by sensor, is 0.95. Therefore, the proposed system accurately detects a trend of the pedestrian traffic in this shopping district. We have further proposed the method to estimate the congestion of this shopping street from the number of pedestrians. The congestion estimation is useful for protecting safety of the shopping street.

Furthermore, we have confirmed that there is a relationship between an audience rate of digital signage programs and velocities of pedestrians, and clarified that accuracy of the attention estimation of signage programs becomes 82.2 [%] by setting an appropriate threshold to velocities of pedestrians. The attention of digital signage programs can be utilized for improving the contents of the digital signage.

Since sensor network and system can collect and store data with 24-hour-a-day, 365-days-a-year, the long-term data about the number of pedestrians and the attention of the digital signage will be utilized for vitalization of shopping streets.

As future works, we will study more parameters related with an accurate attention of signage programs.

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