Estimating the Number of Pedestrians by Doppler Radar

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Abstract — **In the literature, many researchers study human walking inside the room known as gait analysis by video cameras[1, 2, 3]. We are concerned with behaviors of pedestrians outdoor, especially on the public sidewalk. However, we cannot conduct experiments using video cameras from the view point of privacy. In this article, we study the behavior of a group of pedestrians outside with Doppler radar and propose the method of estimating the number of pedestrians in a group. The size of the group is important to investigate the group property in the first place.**

Keyword: *Fourier transform; Kalman filter; Doppler radar*

1 Introduction

We often see a group of people walking side by side on the street. It is dangerous that so big cluster pedestrians are walking in the narrow sidewalk and it may be prohibited in law when the behavior is too dangerous. When these in no independent sidewalk, it will happen to get serious accidents by automobiles and bikes. Therefore, we would like to investigate the property of groups of pedestrians. One of the important knowledges is the size of the group. In this article, we propose a statistical method of estimating the group size.

Doppler radar is useful for the detection of pedestrians[4]. Doppler radar responds to only moving object. In addition, it is able to measure its speed approximately. We use multiple-frequency continuous wave (CW) Doppler radar. The radar can measure not only speed of moving objects but also its distance and direction. In our experiences of analysis of walking, low pass filter (cutting off high frequency of signals) should be useful (described the suitable in the later section). As amplitude of the response of pedestrians is the stronger the response to the Doppler sensor, we arrange the data into thirty divided data set in the descending order. Then, we can construct the new algorithm based on these data assuming the multivariate normal distribution.

2 Experiments

Our experiment conditions are as follows:

- The subjects approach from 40 meters front of the radar and walks to 5 meters to the radar.
- On the way to walk, there are makers to make subjects walk on the straight line.
- When more than two subjects are walking, they walk in a row.
- The subjects walk as usual way.

We use multiple-frequency continuous wave Doppler radar. Specifications of the radar are as follows.

- Frequencies of transmission wave are 24.1950 [GHz], 24.1952 [GHz] and 24.1958 [GHz].
- The number of patches is 3, and its intervals are 1.4 [cm].
- Sampling rates are 50,000 [Hz] for each frequencies.

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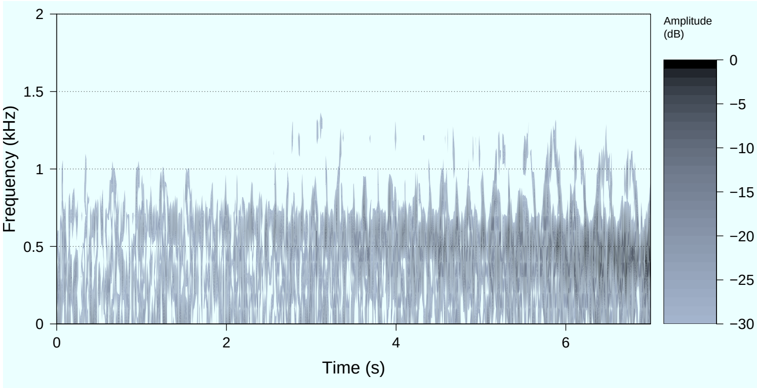

Figure 1: Spectrogram of a single runner

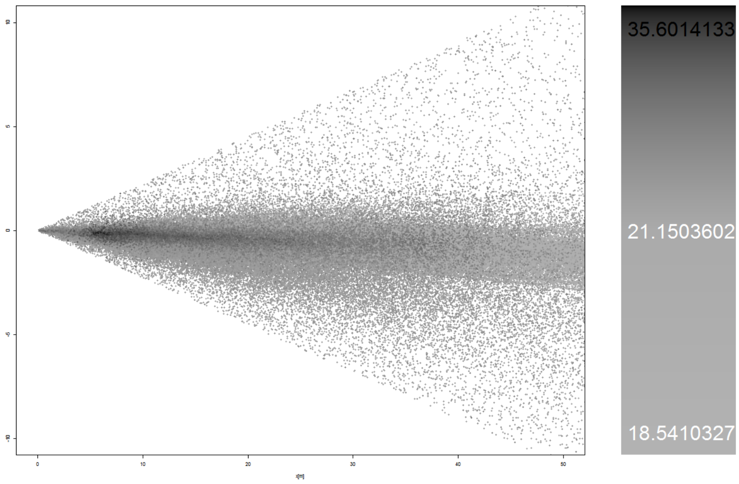

Figure 2: Locations and intensities after removing noises

3 Our method

3.1 Remove the noise

For our analysis, we need to remove the noise from the raw signal of the pedestrian obtained by the experiment, checking the frequency band of the pedestrian by Fourier transform. As a result of checking, we regard that the suitable low pass filter can be set to less than 1,200 [Hz]. Figure 1 is the spectrogram of a single runner for Fourier transform. We can see that the signal over 1,200 [Hz] is very few. Responses appear above this threshold if the walking speed becomes faster than this runner. Then, we set this threshold as the low pass filter upper bound.

Figure 2 is the plot of locations and their intensities of amplitude from the signal. Here we note that noises are removed after applying our low pass filter.

3.2 Estimation of group size

In the following, we briefly explain our detection method. Firstly, we divide signals into the sub data set of every thirty coordinates in descending order of amplitude. For each data set ($\boldsymbol{x}_i$ $(i = 1, \cdots, N)$), we assume that $\boldsymbol{x}_i$ has two-dimensional normal distribution $N(\boldsymbol{\mu}_i, \boldsymbol{\Sigma}_i)$. Ellipses in Figure 3 and Figure 4 show confidence regions of the estimated distribution for a single pedestrian and five pedestrians, respectively. The location of pedestrian group is predicted by estimated parameter $\hat{\boldsymbol{\mu}}_i$.

For estimating the number of pedestrians, we use the eigenvalue $\lambda_2^{(i)}$ which is smaller one in $\hat{\boldsymbol{\Sigma}}_i$. Figure 5 shows the relation of $\lambda_2^{(i)}$ and the Euclidean distance R_i from the pedestrian to the radar for each number of pedestrians. We assume that these parameters follow a state model and Kalman filter for estimating their state with their observed values. The estimated $\lambda_2^{(i)}$'s and R_i's are shown in Figure 6.

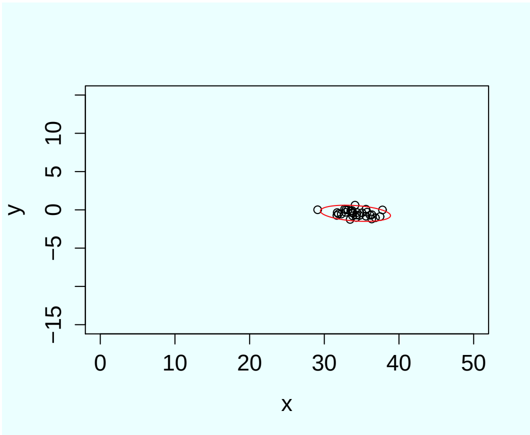

Figure 3: Confidence region of a single pedestrian

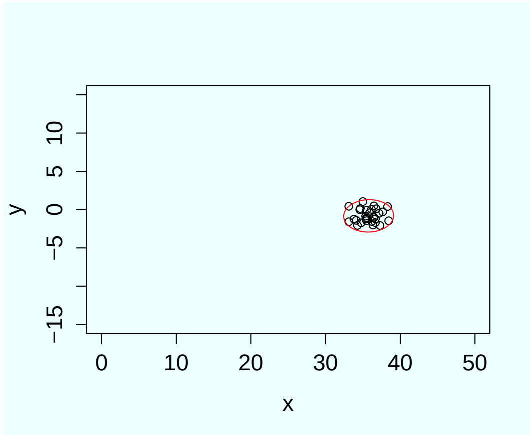

Figure 4: Confidence region of five pedestrians

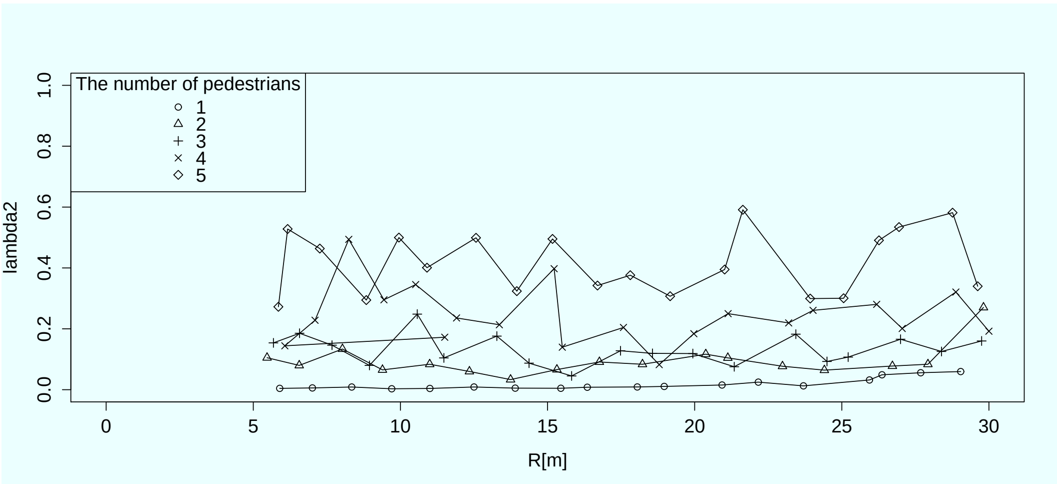

Figure 5: Relation of R and λ_2

4 Results

In this paper, we discussed the problem of the estimation of the pedestrians' group size. Figure 6 shows the relation of $\lambda_2^{(i)}$ and R_i that smoother series of Figure 5 by Kalman filter. We see that series are distinguished for each number of pedestrians when the value of R is small. Therefore, we can distinguish the size of the pedestrian group.

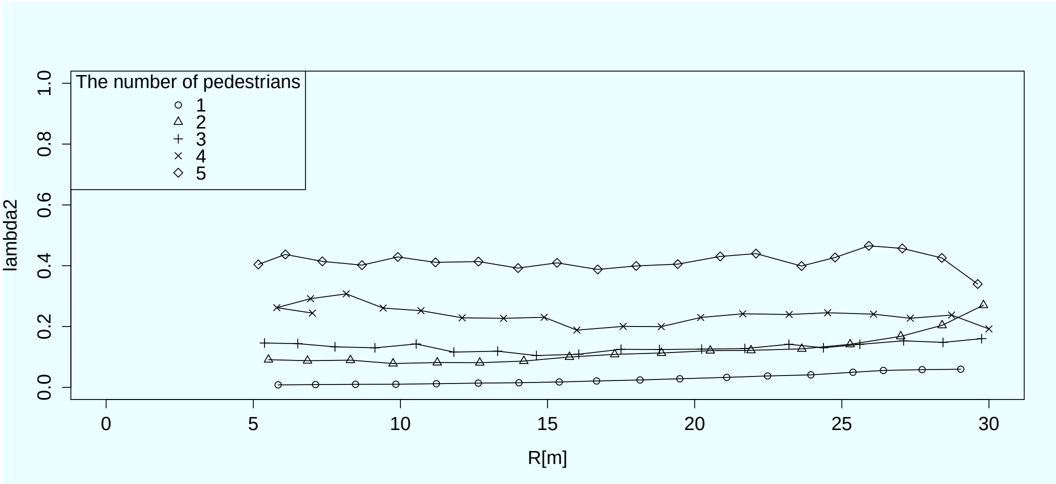

Figure 6: Relation of R and λ_2 by Kalman filter

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