修正ボロノイ法に基づく歩行者密度の測定

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概要

歩行者密度の測定は、「微視的」スケールで歩行者特性を取得するために重要である。歩行者の流れの局所密度の測定としては、スクエア法とボロノイ法が広く適用されている。しかしながら従来のスクエア法とボロノイ法では、低密度の場合に密度を過大または過小評価する傾向があり、歩行者密度の推定には不十分だと考えられる。これに対し本研究では、距離近傍を導入した修正ボロノイ法を提案し、その妥当性を実験データを用いて検証した。まず、スクエア法は密度と速度の明確な関係を再現できないため、二つのボロノイ法よりも劣っていることを示した。さらに、修正ボロノイ法は、高密度の場合において従来のボロノイ法と同等の精度を維持しつつ、低密度の場合において密度と速度の関係をより明確に再現できることを示した。

Measuring pedestrian density using modified Voronoi method

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Abstract

The measurement of pedestrian density is significant for acquiring pedestrian characteristics on a microscopic scale. Both the Square and Voronoi method have been widely applied in measuring the local density of pedestrian flow. However, we have observed the deficiency of the Square and Voronoi method in either overestimating or underestimating the density under low–density case. Therefore, we have proposed a modified Voronoi method to solve this problem. The performance of the modified Voronoi method has been evaluated using experimental data. Results showed the modified Voronoi method could improve the calculation accuracy of the original Voronoi method under low–density case, while keep the outstanding performance of the original Voronoi method under high–density case. In addition, the Square method is inferior than the two Voronoi methods for failing to reproduce clear density-velocity relationship.

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1 Introduction

Similar with vehicular traffic flow, the fundamental diagrams that indicate the relationships between three basic characteristics including density, velocity and flow rate, have also been applied to show the features of pedestrian flow [1]. Nevertheless, pedestrian movements are more flexible than vehicles especially for less restriction on movement dimensionality and more variable shape and speed. Therefore, accurate measurement of the basic characteristics is essential to obtain pedestrian movement features.

Present studies have shown that the Voronoi method, i.e. the measurement of pedestrian density based on Voronoi diagram, could reproduce the fundamental diagram similar to that in vehicular traffic flow [2]. However, despite for the high performance of Voronoi method under high-density conditions, its accuracy under low-density conditions is still unreliable because of its boundary problems. In this study, we try to solve the boundary problems and make Voronoi method more reliable in density calculation.

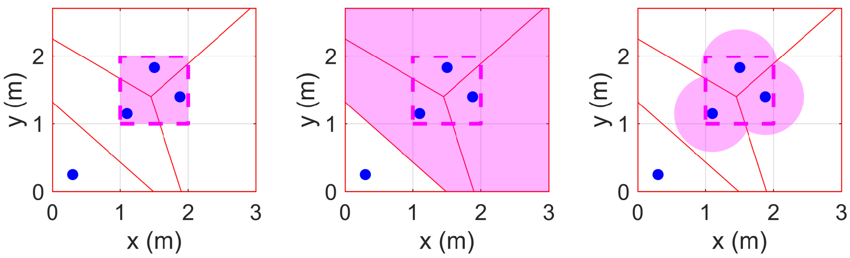
2 Method for density measurement

Density of pedestrian flow tends to indicate the level of crowdness experienced by pedestrians [3]. Three density measurement methods have been shown in Fig. 1, where the density of a unit object region $\{(x, y)|x \in [1, 2]\text{m}, y \in [1, 2]\text{m}\}$ would be calculated. The most widely used method is the Square method, i.e. counting the pedestrian number within the unit region, where the obtained density is 3 P/m^2 in Fig. 1(a). However, on one hand, the possible density value is discrete and might fluctuate largely with subtle change of pedestrian location. On the other hand, the density tends to be overestimated considering that the obtained density is the same with the case when there are plenty of pedestrians outside the object region and the experienced crowdness level is extremely high.

In contrast, the Voronoi method has been shown to be one of the optimal method for density calculation by solving the discrete problem [3]. However, for pedestrians at the outskirts of the crowd, the areas of their Voronoi cells might be quite large or even infinite, which would affect calculation accuracy and even cause calculation errors.

Some studies have tried to solve this problem by arbitrarily setting the maximum area of each Voronoi cell as a certain value, 2 m^2 in [2] for instance. Nevertheless, we still have found the possibility of Voronoi method in underestimating pedestrian density in low-density case for ignoring the details. As shown in Fig. 1(b), the areas of the three Voronoi cells are all larger than 1 m^2. Taking the area limitation as 1 m^2, the density is calculated as 1 P/m^2. Considering that this density is the same with that of the free-walking pedestrians who are not affected by anyone, we presume this Voronoi method has underestimated the pedestrian density especially considering the short distances between the three pedestrians.

To handle with the problems of the two density calculation methods above, we would like to propose a modified Voronoi method through taking the inner area of a circle and the Voronoi cell as shown in Fig. 1(c). The circular radius in this example is set as 0.56 m to guarantee the same maximum area of Voronoi cells as 1 m^2. The obtained density with our modified Voronoi method is 1.27 P/m^2, which we presume is more realistic compared with the Square and original Voronoi method. In the following sections, we would like to take experimental data as examples to further analyze the performance of our modified Voronoi method in density calculation.



(a) Square method (b) Original Voronoi method (c) Modified Voronoi method

Fig.1: Illustration of three methods of density calculation. The density at the subject unit region, where there are three pedestrians inside, is shown in dashed lines. Generally the density is calculated by dividing the pedestrian number with the total area, and the three methods are differentiated by their definition of the 'area'. Please note the maximum area of each Voronoi cell for each pedestrian is set to be 1 m^2 in this example. As a result, the 'area' of the three methods are respectively 1 m^2, 3 m^2 and 2.36 m^2, and the obtained densities are respectively 3 P/m^2, 1 P/m^2 and 1.27 P/m^2.

3 Application on experimental data

The experiment scenario of the selected data can be seen in Fig. 2, which shows a corridor with a wall–shaped obstacle placed at the horizontal middle axis. The 49 participants were required to traverse the corridor and egress from the exit from the left to the right. Video data have been recorded and used to extract their locations using PeTrack software [4].

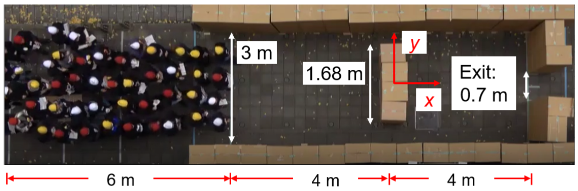
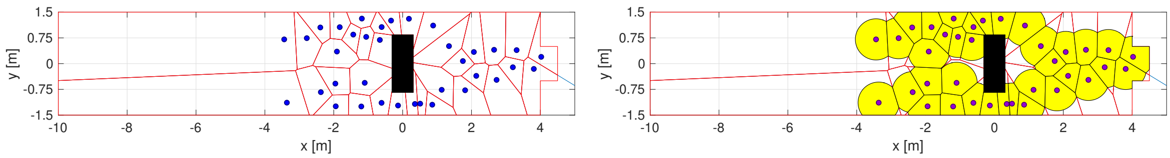


Fig.2: Illustration of experiment scenario.



(a) Original Voronoi diagram

(b) Modified Voronoi diagram

Fig.3: Illustration of original and modified Voronoi diagram in the experiment.

A snapshot of the pedestrian locations and the original/modified Voronoi diagram at a certain time can be seen in Fig. 3, where the circular dots represent pedestrian locations, the black solid square represents the obstacle, the red lines represent the boundaries of original Voronoi diagram, and the black circular curves represent the boundaries of modified Voronoi diagram.

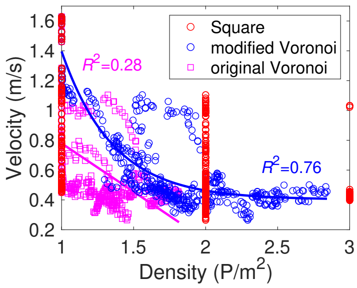
This experiment scenario is chosen because it forms a double-bottleneck case where the local density are more various. On one hand, pedestrians had to decelerate before the obstacle bottleneck for spatial limitation, which results in a high-density case. On the other hand, pedestrians could accelerate after passing by the obstacle because of an extension in walkable space, which results in a low-density case. In the following analysis, we would calculate the local density under low–density case within the unit region $\{(x, y)|x \in [2, 3]\text{m}, y \in [0.5, 1.5]\text{m}\}$ and that under high–density case within the region $\{(x, y)|x \in [-1.5, -0.5]\text{m}, y \in [0.5, 1.5]\text{m}\}$. The reason for choosing the two small unit regions is that the disadvantages of the Square and original Voronoi method are more apparent within small areas.

4 Results analysis

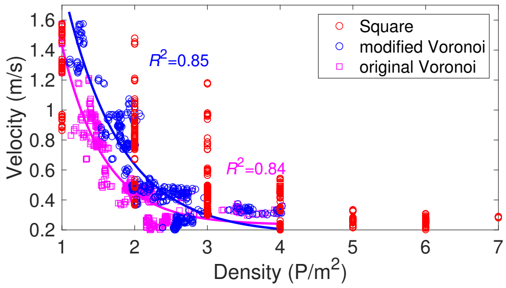
The obtained density–velocity results of the three methods can be seen in Fig. 4. The density values of the Square method are discrete as we have expected, which means the square method is not sufficient in describing density features compared with the two Voronoi methods. Moreover, under the high-density case as shown in Fig. 4(b), the Square method tends to overestimate pedestrian density because 7 P/m^2 has already exceeded the safety threshold in [5]. Considering our experiment was not that crowded and pedestrians were extremely safe, we presume the density ranges of the original and modified Voronoi method are superior than the Square method.

Results of the original and modified Voronoi method will also be compared. As shown in Fig. 4, exponential curves have been applied to fit and show the variation trends of the results. The Coefficient of Determination, i.e. R^2, has been used to evaluate the performance of the two methods. Higher R^2 value indicates that the data are less scattered and the variation features are shown more clear.

Fig. 4(a) shows that under low–density case, the data obtained from original Voronoi method is quite



(a) Under low–density case



(b) Under high-density case

Fig.4: Comparison of density-velocity relationship based on the three measurement methods. For comparison, we set the maximum cell area of both the original and modified Voronoi method as 1 m^2. The sizes of the subject regions for the Square method are also 1 m^2. We have selected 600 samples of the pedestrian locations for density calculation.

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scattered with the R^2 of its fitting curve quite low as 0.28. In contrast, the data obtained from the modified Voronoi method shows a more clear variation trend with the R^2 of its fitting curve much higher as 0.76. Therefore, we have proved that our modified Voronoi method is superior in calculating pedestrian density under low–density case. On the other hand, Fig. 4(b) shows that under high–density case, the fitting curves of the original and modified Voronoi method have similar and high values of R^2. We hence presume the modified Voronoi method has maintained the good performance of the original Voronoi method under high–density case.

5 Conclusion

Despite both the Square and Voronoi method has been applied in reproducing the fundamental diagrams, we have illustrated their deficiency in either overestimating or underestimating pedestrian density under low–density case. To handle with this problem, we have proposed a modified Voronoi method through adding a circular boundary to set the maximum area of Voronoi cell. The performance of the modified Voronoi method has been evaluated using experimental data.

Results showed that the Square method fails to reproduce clear density-velocity relationship compared with the Voronoi methods. Meanwhile, the modified Voronoi method is superior in reproducing more reliable density-velocity relationship under low–density case, and keep the performance of the original Voronoi method in reproducing reliable density-velocity relationship under high–density case. Conclusions in this paper are expected to help improving the accuracy of density-estimation and therefore obtaining more reliable pedestrian movement features.

6 Acknowledgement

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