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A Crowd Pre-warning System Based On Mobile Locators and Behavior Prediction

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Abstract— In the past decades, Stampede accidents occurred around the world. In order to avoid these horrible emergencies, we designed a three-part system based on the mobile locators in smart phones to warn the related departments of the crowd gathering. This paper has two contributions:

First, we apply routing predictions to crowd gathering, so we can predict the crowd density in specific areas in the future period time, which is important for pre-warning of crowd gathering. Second, an integral crowd gathering system is designed for pre-warning of crowd gathering. The system consists of three parts. All the three parts form an entirety while they are mutual independent.

Keywords— ARMA model, Crowd Pre-warning, Markov chain, Route Prediction

I. INTRODUCTION

People often gather during festivals or important events. Event organizers should improve safety standards and reduce the risk of accidents. The existing pedestrian flow control mechanism for large-scale population cannot simply deal with this situation. As the number of people cannot be determined, and the behavior of the crowd is highly unpredictable. Pre-warning helps to quickly implement adequate measures to mitigate potentially hazardous situations. To achieve this purpose, we need to understand the behavior of people in real time. At present, people tend to use video surveillance and pattern recognition to achieve this target[1][2][3][4].

Video-based method has defects. The cameras cannot get the images out of their vision and the information obtained by different cameras is still very difficult to combine[5]. Besides, the accuracy of video surveillance may be affected by the weather. So researchers came up with radio-based pre-warning mechanism for crowd[6][7].

Nowadays, crowd pre-warning through mobile phone has some advantages. First, there is no need to purchase devices for video surveillance. Second, receiving signals are not affected by weather. If the crowd density can be predicted ahead of time, we can warn the improper crowd in advance and reduce the risk of potential accident.

We proposed a three-part system based on the mobile locators in smart phones to warn the related departments of the crowd gathering. The rest of this paper is organized as follows: in Sec. 2, we briefly review some basic theory cited. We then present three main steps to design crowd gathering pre-warning system in Sec. 3. In Sec. 4, the crowd alert system is analyzed and verified. Finally, Sec. 5 concludes the paper and suggests the further research.

II. REALATED WORK

The system includes three parts. The first part is ARMA model used for correcting location points collected by locators. The second part is a route prediction system based on adaptive multi-order Markov model which is established for predicting the users' future position and the time for which users stay in that position. The third part is the pre-warning system for crowd gathering.

Aimed at designing a crowd gathering alert system, firstly this paper employs an ARMA model to correct the location point with deviation to a single person. Next, in order to predict the behaviors of a group exactly, the system has to predict the individual behavior precisely. This paper employs the self-adaptive Markov model to predict the possible routes which a passenger may reach in some time.

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Finally, this paper imports time into the prediction model to design the algorithm, thus calculate the exact crowd density within a location.

A. Correction of a location point on mobile terminals

A cell phone usually locates based on base stations, GPS or Wi-Fi. The locating by cell phones may deviate and affect the ultimately prediction, this paper employs an ARMA model to correct the location point with deviation to obtain a precise location point.

Firstly, we build a model of the time sequence with ARMA. It requires the sequence should be steady. If not, we should preprocess the time sequence. The flow diagram of location points correction is shown as figure 1.

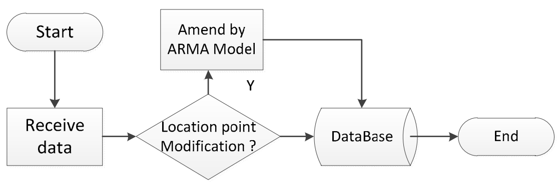

Figure 1. Flow diagram of location points correction

B. Markov passenger route prediction based on mobile locating

The location points should be transformed into areas because the points are set too intensively. First divide the map. Then calculate which area the point is in according to its longitude and latitude. Each area regards as a route point, all route points a user goes through make up one's history route. We can build a Markov model with the history routes to predict the possible route point the user may reach next time.

This paper directly stores users' location points, the arriving time and the departure time of that point by the order of time specific to single passenger's history route. In the server, a dedicated file is created for each user to log information of route points one has passed. Deleting remote route points and adding recent ones will guarantee the information used to build Markov model is up to date and avoid concept drift.

In addition, the number of route points used to build Markov model cannot increase without limitation, so we should restrict it. This paper sets a restriction of 10,000.

This paper predicts users' next route points and the next after next ones. The next point predicts the most probable one among the points which may be reached. The next route point aim at crowd gathering alert while the next after next ones aim at personalized recommendation according to the points which users will reach. Crowd pre-warning requires to calculate the number of people in the next period of time, so accurate values are needed, and personalized recommendation can provide several recommendations for users.

Steps of building route prediction based on Markov model are shown as follow.

- Gather users' location point information from mobile terminals.
- Convert location points into route points with the given formula.
- Log route points went through by users into dedicated files by the order of time.
- Load the 5 most recent route points.
- Build Markov model with users' route point files.
- Predict the most probable route points the user will reach at the next time and the time next to the next time.

Flow diagram of route prediction based on Markov model is shown as figure 2.

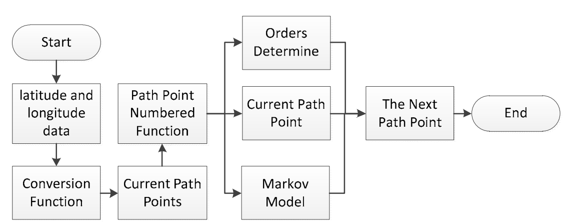

Figure 2. Flow diagram of route prediction based on Markov model

III. CROWD PRE-WARNING SYSTEM

Mobile terminals are used to locate the current location of mobile phone users. The mobile phone will upload the location of information and the corresponding time information to the server in real time. The server side through the establishment of the ARMA model for the user to upload the positioning point to distinguish, if there is error, then modify the error. Then, according to the conversion algorithm between the latitude and longitude and the route point, the upload data is converted to the number of route points. After that, the second chapter provides the method to establish the Markov model, the next step to predict the user to reach the point of the route and the time required to reach the next route point.

Theoretically, the population density can be calculated by the number of cell phones in a specific area and even around the world. However, this action costs a large amount of storage and computing resources. Moreover, practically, only parts of the critical areas have the possibility of group accidents frequently. So, only the specific critical areas require calculating. The system creates a file for each critical area on the server. If the next predicted route point of the user is in the critical area, the user number, the time to reach the next route point and the time to leave the next route point are saved to the file as a structure. Mark the current number of people in critical areas (which is easy to get) as CPN.

The use of self-adaptive multi-order Markov model can predict the areas which the user will go through in the future. But to predict the population density in a specific area, it is necessary to predict the users' residence time in a certain area. In this paper, we calculate the residence time of the users in the same area and calculate the average value as the time of the users stayed in the specific area. The areas which will be went through and the residence time can predict whether the user will stay in the specific area in the next period of time, so we can calculate the population density of a specific area.

In this paper, we set the current time as the starting point and calculate which area each user is belong to and the number of people in a specific area by 0, 30, 60, 90, 120, 150 and 180s later from the current time. Thus we can get the population density of a specific area.

As the crowd gathering place varies, it is not suitable to use the absolute area to calculate the population density of the gathering area. The acreage of critical area needed to be alerted (which is marked as CA) should be set according to the actual situation. Population density of critical area is marked as CPD,

$$\mathrm{CPD} = \mathrm{PPN} / \mathrm{CA} \tag{1}$$

For the different sites, the population density thresholds of each region vary. This requires experienced organizers to set the actual situation. The critical area of the population density threshold is marked as PDT. When CPD is greater than PDT, the cell phone users will be alerted not to enter the critical areas.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, we first employs the ARMA model to modify the deviation of the location point. Secondly, to predict the behavior of the group accurately, we must precisely predict the behavior of individuals. This paper employs a self-adaptive Markov model is to predict the route of the pedestrians in the future for a period of time. Finally, this paper introduces the time factor into the prediction model to design algorithm because of the mobility of human, and it can calculate the number of people in the specific areas in real-time through the mobile terminals, thus accurately calculate the population density of specific regions and the recommend routes.

Collect the user's location point information through the mobile terminals and import their latitude to the E-views software. Then draw the timing diagram (shown as figure 3) in the software.

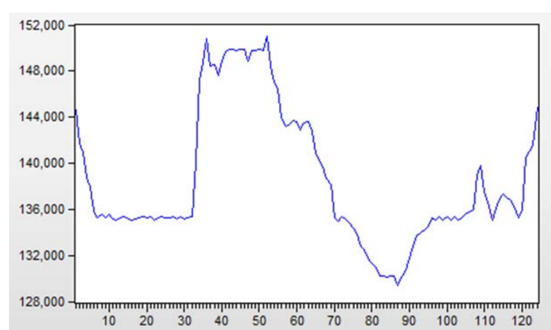

Figure 3. Sequence chart of location points

In figure 3, the sequence is unstable, so it should make difference on the original sequence.

The first-order time sequence diagram is shown as Figure 4:

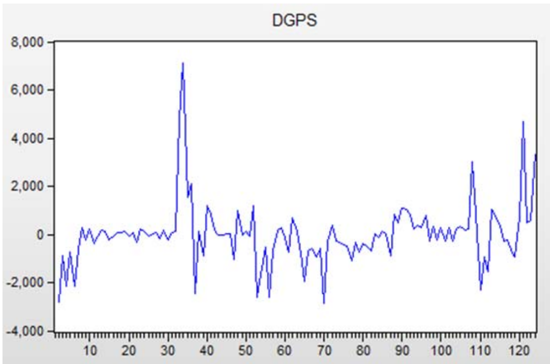

Figure 4. Time series diagram after first-order difference

In figure 4, the value of the sequence fluctuates around zero, it has stability. Further ADF test also shows that the time sequence is stable in a first order difference.

In the sample test of the pedestrian path, the system collected 8075 pairs of latitude and longitude and get 5650 points after conversion. It uses the first 5000 points of the routes as historical data to build the self-adaptive Markov model while the last 650 points are used as test data to calculate the accuracy of the Markov model. The area is set to 100m*100m. The prediction accuracy of the first order Markov model and the adaptive multi order Markov model are tested respectively, and the results are shown in table 1.

According to table 1, the self-adaptive Markov model sharply improved the prediction accuracy of the model. This accuracy has been enough to apply to the crowd gathering alert.

TABLE I PREDICTION ACCURACY COMPARISON OF FIRST-ORDER MARKOV MODEL AND ADAPTIVE MULTI-ORDER MARKOV MODE

Samples / Markov model	Total number of test samples	Correct number	Accuracy （%）
First order Markov model	649	472	72.73
Adaptive multi order Markov model	645	547	84.81

In this paper, the region area is divided into 50m*50m or 200m*200m. Then the system uses the self-adaptive multi-order Markov model to calculate the accuracy of the model. In the case of 50m*50m, 6835 route points are obtained by conversion function. In the case of 200m*200m, 3463 route point data are obtained. Their accuracy is shown in table 2.

TABLE II PREDICTION ACCURACY COMPARISON OF DIFFERENT REGION PARTITION

Samples / Region size	Number of test samples	Correct number	Accuracy （%）
50m*50m	830	651	78.43
100m*100m	645	547	84.81
200m*200m	458	406	88.65

From the table above, the accuracy rate is gradually increasing when the partition area increases. Due to the limitation of GPS positioning accuracy, positioning errors will occur. This positioning error may probably result in discord between the conversed route points and the actual route points of the mobile terminals. In addition, when the mobile terminal moves at the edge of the route point, the route points may change frequently. The changes will also decrease the prediction accuracy. The probability of these two circumstances decreases when the partition area increases. So we increased the partition area to improve the accuracy. If the area is too small, the prediction accuracy will reduce while the computing complexity improves. So the partition should not be too small. If too large, though the prediction accuracy improves, it will affect the effect of the crowd gathering alert because the crowds often gather in a small area and the system estimates inadvisably whether excess crowd has gathered. Therefore, the partition should not be too large. The table above shows that size of 100m*100m combines the accuracy, the computing complexity and the requirement of crowd gathering alert, so the size is more appropriate.

The ARMA model, the adaptive multi-order Markov prediction model and the crowd gathering algorithm are established in Sec. 3. The overall framework of the crowd gathering pre-warning system has been completed, the flow chart is shown as figure 5.

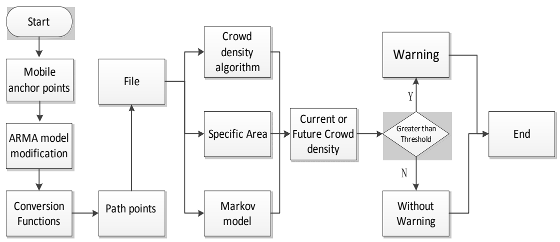

Figure 5. Flowing chart of crowd gathering pre-warning

In this paper, the experiments is conducted according to the flowing chart. This paper simulates 10,000 users, and sets the crowd warning area where need to be monitored. The initial area is set to 32km *18km, so its latitude and longitude of the cell number ranges are 0-320 and 0-180. Take the center position as the specific area, so the latitude and longitude of the specific area number is (160, 90).

In reality, people always take the initiative to gather venues, then the probability of the user moving toward a specific area is set to be larger than the other direction. Since this map will be divided into one rectangular area, so the next area the user will reach are down about four rectangular areas. This article calculate the distance from the specific area to the four regions by formulas 2, The nearest regional rate is set to 50%, The remaining three are set to 17%,17% and 16%。

$$\text{distance} = (lon - 160)^2 + (la - 90)^2 \tag{2}$$

Where distance represents the distance from the target area to the specific area, lon and la represent longitude and latitude number of rectangular area respectively.

It is necessary to set the residence time in the next area for each user. The residence time is set to 1200s if the next field is a specific area. Or it will be set in accordance with the following. The residence time divide into four intervals. Respectively：[20s-50s), [50s, 100s), [100s, 300s), [300s, 600s). Each rectangular area is set to 100m * 100m area, it is most likely to go through a rectangular region within 20-50s considered the pedestrian walking speed, therefore, the probability passing through this area is set to 70% range, and the other three are 15%, 10% and 5%.

The current number of pedestrian in specific area is calculated per second, so is the next three minutes' pedestrian number. 3 minutes will be divided into six time periods, and statistics the number of pedestrian at the 7 time points in specific area.Firstly, the number of specific area in 18000s (5 hours) is calculated which is divided into 9 parts. Averages is calculated for each group of data. Plotting the averages as figure 6.

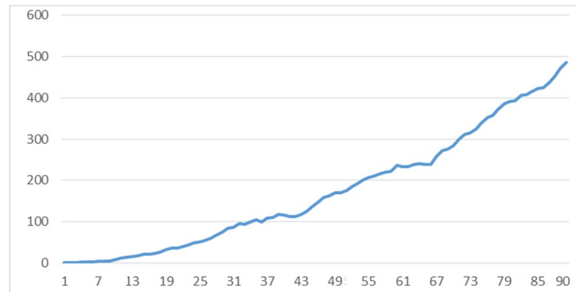

Figure 6. Pedestrian number changing in 5 hours

As shown in figure 6, the number of pedestrian in specific area increase gradually as time goes by, it shows a cluster effect which is compliance with the prior probability setting.

The difference in number of pedestrian at the moment of 0s and 180s is compared as figure 7 shows：

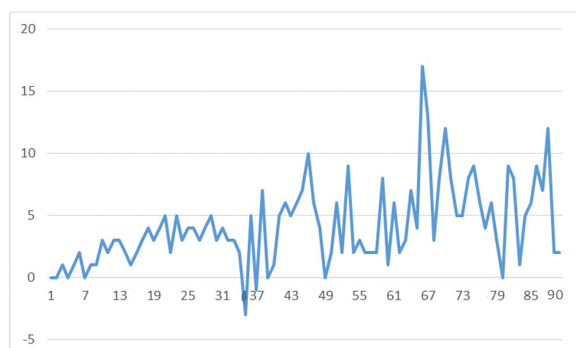

Figure 7. Difference of 0s and 180s in the number of people

As shown in figure 7, the difference is positive mostly, it means that there are more people at 180s time point than 0s time point. The number of entering a specific area is greater than leaving in 180 seconds which is in line with the probability setting.

In order to verify whether the number of people in specific area will be stable after a certain time, the changes in 180000 seconds (50 hours) is calculated. As it shows in figure 8, there are 90 data points. Each point represents the average of 2000 data points.

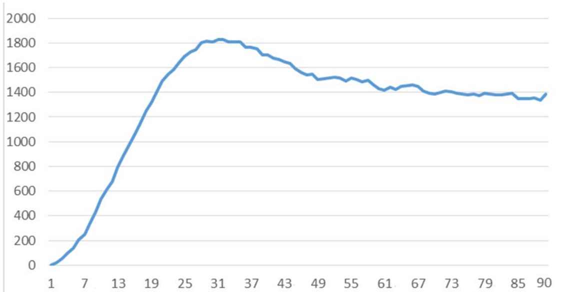

Figure 8. The change of the number of people in 50 hours

As shown in figure 8, the number of people of specific area increases rapidly in 0-30 range, while it begins to reduce slowly in 30-60 range. At last the number of people stabilized at around 1,400 in 60-90 range. The result of the simulation experiment shows that the system works normally and can calculate the current population density and that of next period of time in reality.

V. CONCLUSION

To prevent the stampede accidents, many researchers have done much work. The video surveillance method is used mostly. Since the method based on video surveillance has many limits, and the smart phones with integrated locator chips are widely used, we proposed a system based on cell phones. In this paper, a crowd pre-warning system is designed based on route prediction. The system is divided into three parts. The first part is a location point correction system, the second is the route prediction system, and the third is the crowd pre-warning system. All the three parts form an entirety while they are mutual independent. The ARMA model is employed to correct the location points, it can correct the location points with large deviation. Using adaptive Markov model in route prediction can effectively predict the users' next position. We also designed a density calculation method for the system.

The proposed system collects location data via mobile locators. The method can provide high accuracy but cost much energy. Energy saving is important for smart phones, if the power consumption can be reduced, the user's experience will effectively improve and it will be conducive to the promotion of related applications. Therefore, Wi-Fi locating method may be employed in the future. In addition, the divided area block size can be adjust for different situations in order to achieve a better prediction.

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