Dynamic Guidance for the Evacuation from Disaster Area based on Crowd Density

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Abstract- **In cases of disasters, emergency evacuation guidance system is needed. The design of most emergency evacuation guidance systems concerns the avoidance of the disastrous area, and the shortest escaping path; however, such design may lead to overcrowding in some areas. This study assesses the density of crowds on evacuation routes, and developed a dynamic guidance system, which sets the priority in the following order: avoid disaster area, crowd, and path. It can provide proper evacuation guidance to avoid overcrowding**.

Keywords- **Foreground extraction, Evacuation, Guidance**

1. INTRODUCTION

With dense population and small land area, Taiwan provides limited living space, and most buildings are high-rise buildings. Hence, disasters may lead to unimaginable outcomes. According to the statistics of the National Fire Agency, Ministry of the Interior R.O.C, the average number of fire disasters per year is 15,000, among those, mostly are building fires [6]. As Taiwan is situated on the fault, earthquakes frequently occur. Thus, an effective and safe evacuation plan is crucial to minimize the damages to the public and society.

At present, wireless sensor network (WSN) has been applied widely. The WSN is a system consisting of one or more wireless data collectors and many sensors, which gather data from the environment. Many studies have applied sensing units to the design of evacuation safety [12][14]. Some set up the WSN on buildings to detect the occurrence of fire accident in advance based on temperature change. Considering the crowding situation during evacuation, hierarchical concept has been applied to notify the evacuation, and guide the crowds to safe areas [13].

The design of most evacuation guidance is to avoid the disaster area, and provides the shortest evacuation path. However, the people following the evacuation guidance may aggregate into large crowds, and cause overcrowding. To address this problem, Wang [15] proposed an evacuation guidance algorithm that includes the factor of crowd density. However, in the actual environment, there is no effective algorithm for crowd density sensing and concrete strategies at present.

Chen [16] used the AC/DC line communication, which is different from the ordinary power line communication. The system communicates through AC line during normal operation, but switches to DC line during power interruption to provide uninterrupted fire detection system. It can solve the problem of communication interruption of fire systems during power interruption disaster area.

By combining the concepts from above two studies, this study proposes the Disaster Sensor System Architecture, as shown in Fig.1. The video sensors set on the evacuation path and the image processing technology can provide information on crowding, prevent injuries due to overcrowding, update on the routes of crowd movement, and propose an effective algorithm for disaster evacuation.

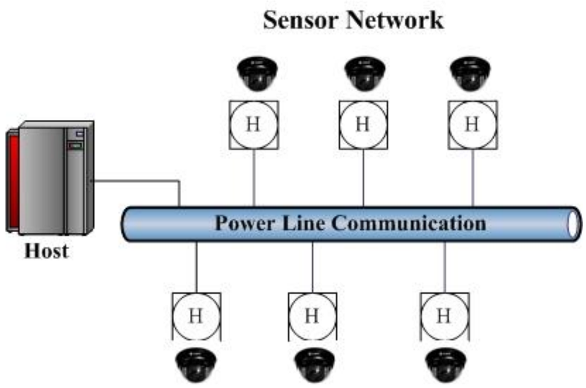

Fig.1 Disaster Sensor System Architecture

2. RELATED WORK

2.1 Factors affecting the evacuation duration

The conventional computation for disaster evacuation is based on the fluid computation model. It assumes that the evacuators are alert, capable and moveable [3]. Thus, when designing evacuation facilities, the priority is on the evacuation duration. From practical and theoretical viewpoints, the factors affecting the evacuation duration are crowd density, stairway type, conditions of evacuation passage, and reasonability of evacuation route.

In general, when the crowd density is high, the required evacuation duration is longer. When the crowd density is over $0.25m^2$/person time, the walking speed is limited to 0 and the passing speed is 0. If the evacuation route is not concise, smooth, or has obstacles, such as deadlock or doorsill, the evacuation speed will be affected. Thus, crowd density is one of the most important factors in the evacuation [1].

2.2 Foreground extraction

With advancement in technologies, the computation speed of computer is faster; hence, using computer graphics identification technology in surveillance has been widely applied. When assessing crowd density, the variable regions of the motion images need to be extracted from the background first.

The common detection methods include: Huang et al. The studies [7][9] used the background subtraction method to detect the foreground, and calculated the pixel by perspective conversion to assess the crowd density. Coianiz et al. [11] applied fuzzy theory after evaluating the foreground pixel, and classified the density gradients. Ma [8] captured grain characteristic from the foreground and divided the images into many cells by perspective conversion to assess the crowd density.

3. SYSTEM ARCHITECTURE

The system utilizes the foreground extraction method to assess the crowd density on the evacuation path, and applies the evacuation guidance algorithm to increase the evacuation effectiveness.

A video camera is installed on each evacuation path, at downward angle to shoot in the same direction as the evacuation path.

The node at the exit is called as exit node, which has the lowest weight, 0. Other nodes have different weights, according to their distances from the hop count of the exit.

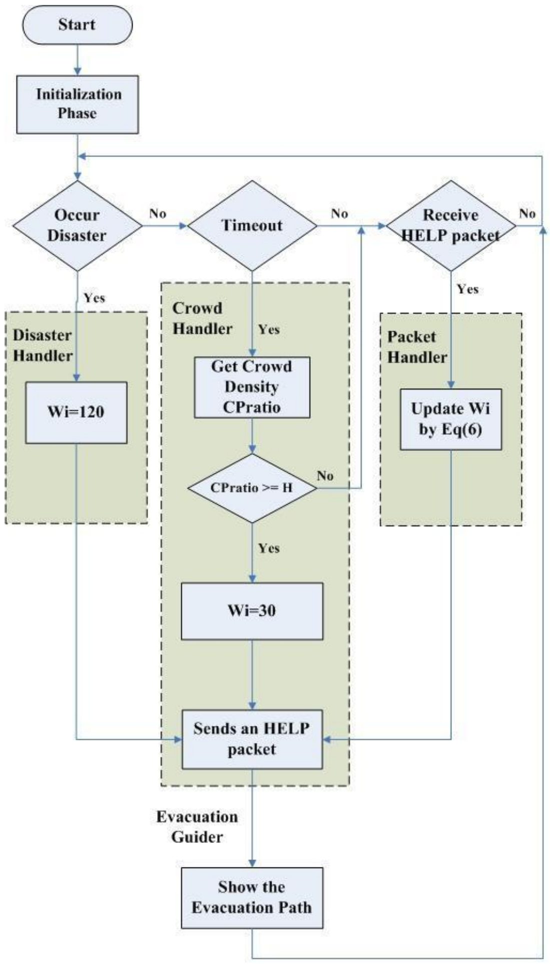

Fig.2 Software System Architecture

The software system architecture for each monitoring point is consists of the following blocks, as shown in Fig. 2: Initialization Phase, Disaster Handler, Crowd Handler, Packet Handler and Evacuation Guider.

3.1 Initialization Phase

At the system is set up, the initialization phase is conducted to assign an initial weight to each node.

Each Exit node sets its weight to 0 and sends an INIT packet with a parameter 0 to all the neighbor nodes. All nodes are set to be with undefined weight.

If a node receives an INIT packet, and if the weight of the packet, P_p, is small than its weight, $W_{i,}$, it updates its weight to be P_p+1, and sends an INIT packet with parameter P_p+1 to all other neighbor nodes who's weight is undefined or greater than $W_{i,}$. Otherwise, aborts the INIT packet.

Each node will record the weights of all its neighbor nodes.

3.2 Crowd Handler

Since the camera in this system and the environment are fixed, a background image should be established based on Eq(1).[5]

$$Ibk(u,v) = median\left(I_k^{(i)}(u,v)\right), i = 0,1 \cdots, n-1$$

(Eq1)

Where

k is r, g, or b. It is representing R, G, or B channel of RGB color space respectively.

$I_k^{(i)}(u,v)$ is the i_{th} input image's color value of channel k at point (u,v);

n is the sequence number for pixels in the establishment of image;

median(.) is the function for getting median value.

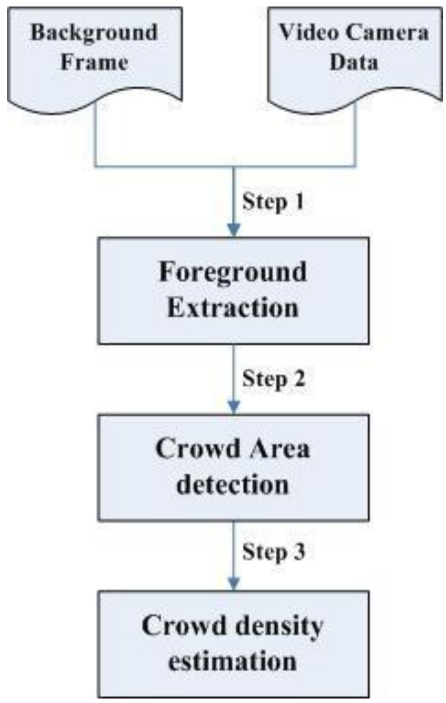

Fig.3 Crowd Density Estimated Procedures

To determine the crowd density on the evacuation path accurately, the system operates, as shown in Fig. 3in the following steps:

Step 1.Foreground extraction: It detects the crowd on the evacuation path.

If the Crowd handler activates, an image $Ik(u,v)$ is captured from the camera.

Based on Eq.(2).[10], the binary foreground image $Im(u,v)$ is set to the difference between the inputted image $Ik(u,v)$ and background image $Ibk(u,v)$ if the difference is larger than the threshold Th ; Otherwise, it is set as the background. An example is shown in Fig.4(a)(b)(c).

$$Im(u,v) = \begin{cases} 1, if \|Ik(u,v) - Ibk(u,v)\| > Th \\ 0, otherwise \end{cases}$$

(Eq2)

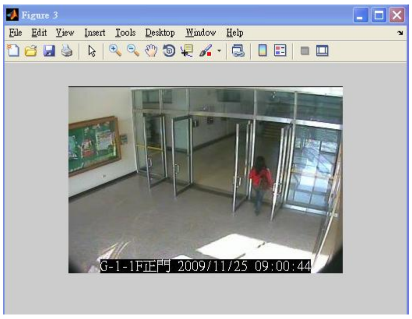

Fig.4 (a) Original Image

Fig.4 (b) Background Image

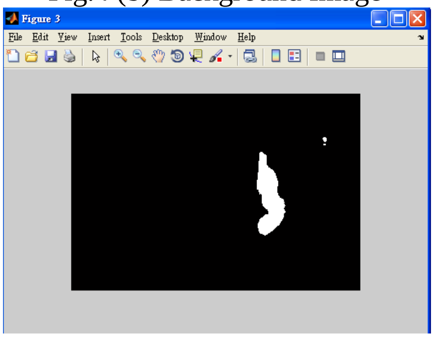

Fig4. (c) Detection of Foreground Object

Step 2. Crowd Area detection : It reduces the image noise of foreground image by binarizing , dilation , and erosion operation.

Then, apply the method proposed by the foreground image is scanned from the top to bottom, and left to right, to obtain the most possible crowd area(e_i).

Moreover, the size of crowd areas need to be normalized with respected to the distance from the camera.

By the pixel normalization method proposed in [2], each foreground pixel is normalized by multiplying a weighting factor as shown in Eq. (3).

$$w_i = 1/area(e_i) \quad \text{(Eq3)}$$

Finally, the normalized result for total foreground crowd pixel is achieved by Eq. (4).

$$\mathrm{CP} = \sum_{\mathrm{i=1}}^{\mathrm{i=Image\ length}} w_i \cdot FP(i) \cdot sin\,\theta_i \quad \text{(Eq4)}$$

Where

CP is the Normalized result for total crowd area

$FP(i)$ is the foreground extraction result for pixel *i*, hence it is 1 if *i* is the foreground but 0 if not.

$\sin\theta_i$ is the angle between the camera and the position of pixel *i*.

Step 3. Crowd density estimation : Since the capacities of the evacuation paths vary with the sizes of evacuation paths, the estimated crowd area on the evacuation path, CP, will be calibrated by t the maximum crowd area, $\mathrm{CP_{max}}$, as shown in Eq. (5):

$$\mathrm{CP_{ratio}} = \mathrm{CP}/\mathrm{CP_{max}} \quad \text{(Eq5)}$$

$\mathrm{CP_{ratio}}$ is used to determine the level of crowd density, as shown in Table 1.

Range Of $\mathrm{CP_{ratio}}$	Level Of Crowd Density
< 0.2	Very Low (VL)
$0.2 \leq \sim < 0.4$	Low (L)
$0.4 \leq \sim < 0.6$	Moderate (M)
$0.6 \leq \sim < 0.8$	High (H)
≤ 1	Very High (VH)

Table1 Definition Level Of Crowd Density

However, the evacuation path is inadequate to be changed frequently. A timer is setup to timeout every 5 seconds. The crowd handler is activated only when the timer is timeout.

When the crowd density on the evacuation path is over H, the weight of the node is increased based on the level of crowd density. The node sends an HELP packet to the nearby nodes with its weight.

3.3 Disaster Handler

When the node detects the disaster, the Disaster Handler is activated. It sets its weight to be a high value, 120, in our example, and sends an HELP packet to the nearby node with parameter 120.

3.4 HELP Packet Handler

When the node A_i, with weight W_i, receives an HELP packet with a parameter P_p, from node A_p ,it updates the recorded weight of the A_p to be P_p. If all other nearby nodes A_j with weight $W_j < W_i$, then abort the packet. Otherwise, apply Eq. (6) to update its weight.

$$W_{i\_new} = \left[(P_p + MIN_{all\ j}(W_j))\ /2\right] \quad \text{(Eq6)}$$

Where

$MIN_{all\ j}(W_j)$ is t is the minimum value among all W_j

The weight of the node is set to be W_{i_new}

If there exist some nearby nodes A_k whose weight $W_k > W_i$ and $W_k < W_{i\_new}$, then send the HELP packet with W_{i_new} to all A_k.

All exit nodes, and disastrous nodes ignore HELP packets.

3.5 Evacuation Guider

It shows the evacuation path to the neighbor node with the smallest weight.

4. IMPLEMENTATION

This study used Matlab 7.6 to process the images. The system interface, as shown in Fig. 5, is divided into two parts: real-time monitoring and video testing. The real-time monitoring is connected to the camera to provide real-time images, which can be used as background images for normal situations, image update speed, and binary image threshold. In video testing, after opening the AVI files, the system automatically converts the videos into JEPG files, so that users can select background images. After processing the captured images, the crowd density on the evacuation path can be calculated.

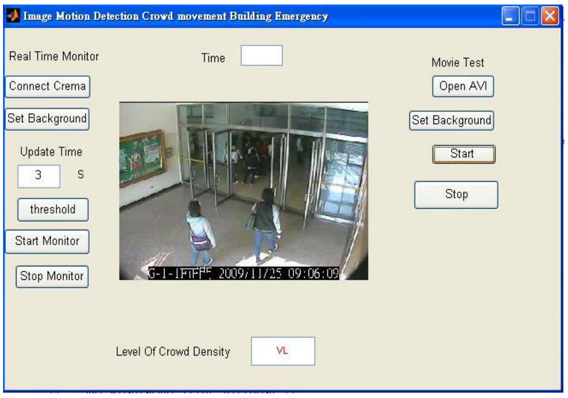

Fig.5 System Interface

4.1 Environment for initialization

To further describe the operation of system, this study established a system test environment after the initialization, as shown in Fig. 6. Where exit nodes are E1, E2, E3. Other nodes denoted as Ai are corridor nodes.

Each node Ai is assigned with an initial weight, W, based on which the each node can be guided into the exit by the initialization phase.

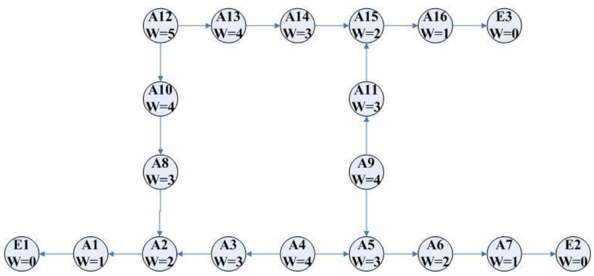

Fig.6 Node Initialization

4.2 Disaster cases

If the system detects the disaster at node A14, the weight of A14 is increased to 120. The repulsion is used to divert the crowds outward, namely toward the nodes with equal or less weights. When the weight of node is equal or less than that of nearby node without action, Eq. (6) is applied to increase the weight. The steps are repeated to achieve outward guidance to safe exits. The result is shown as in Fig.7, the evacuation path $A12 \rightarrow A13 \rightarrow A14$ is changed to $A14 \rightarrow A13 \rightarrow A12$, the evacuation path $A9 \rightarrow A11 \rightarrow A15$ is changed to $A15 \rightarrow A11 \rightarrow A9$ to avoid the disaster area.

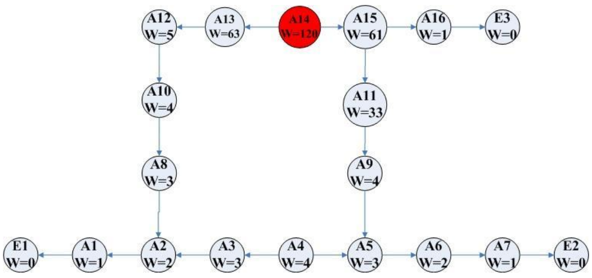

Fig.7 Design of evacuation order

4.3 In case of disaster, and one exit passage is crowded

When disaster occurs at A14 and evacuation has been implemented for a period of time, Node A1 detects that its crowd density has reached H, and the path is crowded. According to design of evacuation guidance in this study, the priority is to avoid the disaster area, followed by the crowd and path. However, the calculation of guidance path in actual situation starts from the lowest and most dangerous layer, and the weights increase as the danger level rises.

As shown in Fig. 8, the weight of A1 is increased into 30. The outward guidance by repulsion is included in the guidance algorithm to obtain the first result, then, based on this result, the weight of A14 is increased to 120, and the algorithm produces the second result. Lastly, the path $A4 \rightarrow A3 \rightarrow A2 \rightarrow A1$ is changed to $A1 \rightarrow A2 \rightarrow A3 \rightarrow A4$, so as to avoid the crowded area.

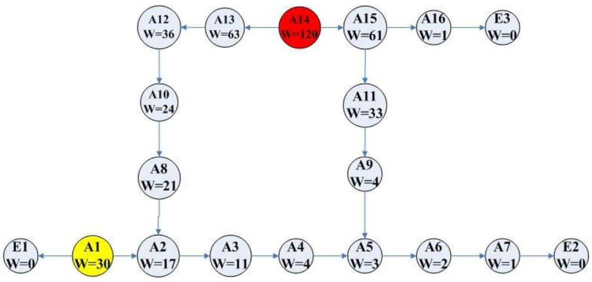

Fig.8 Design of evacuation order

5. CONCLUSION

This study proposed a dynamic disaster evacuation guidance system to avoid overcrowding during evacuation. The system uses the foreground extraction method to compute the crowd density and assess the danger of crowding. The evacuation guidance system with the condition of crowd density is more effective in preventing overcrowding during evacuation. In the design, the priority is given in the following order: avoid disaster area, crowd, and path. When two paths are crowded, the density obtained from the image detection is for computation, in order to avoid guidance errors. Lastly, this study proposed a complete set of evacuation guidance algorithm to guide the crowds to safe evacuation paths and minimize unnecessary injuries.

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