Fuzzy neural network based scenario features extraction and mapping model for crowd evacuation stability analysis

Rongyang Zhao\textsuperscript{1}, Qiong Liu\textsuperscript{1,}\textsuperscript{*}, Cuiling Li\textsuperscript{2}, Daheng Dong\textsuperscript{1}, Qianshan Hu\textsuperscript{1} and Yunlong Ma\textsuperscript{1}

\textsuperscript{1}CIMS Research Center, Tongji University, Shanghai 201804, China.
\textsuperscript{2}College of Electronic and Information Engineering, Tongji University, Shanghai 201804, China.

*Corresponding author e-mail: hhliuqiong@163.com

Abstract. The scenario features of large-scale crowd evacuation are complex and uncertain, leading to difficulties in making intelligent decisions for crowd evacuation stability. Therefore, this paper utilizes a fuzzy neural network method to analyze and extract main crowd scenario features. Subsequently, the stability characteristics as evacuation historical backtracking can be the attributes for evacuation stability judgment. Finally, we can obtain mechanism causes of instability and state evolution law of crowd evacuation, to intervene and guide the large-scale crowd evacuation.

1. Introduction

With the rapid development of social economy and culture, various public places are undertaking more and more large-scale crowd gathering activities\textsuperscript{[1]}. In recent years, a large number of crowded stampede incidents have occurred frequently, while the causes are complex and unpredictable. As a result, it is urgent to excavate intelligent method to analyze the root causes of the unstable crowd and study the evolution mechanism of crowd stability\textsuperscript{[2]}. In this paper, we use a fuzzy neural network modeling method to extract and map the features of crowd evacuation scenarios and evacuation state evolution. With the network self-learning ability, we can obtain mechanism causes of instability and state-evolution rules of crowd evacuation, to intervene and guide large-scale crowd evacuation.

2. Fuzzy Neural Network

Fuzzy neural network uses the self-learning ability to optimize fuzzy rules, membership functions and fuzzy decision algorithms in fuzzy logic systems\textsuperscript{[3]}. It transforms the learning results of neural networks into the rules knowledge of fuzzy logic systems, which is more conducive to the interpretation and utilization of the knowledge base. It is very suitable for the evaluation and diagnosis of complex objects\textsuperscript{[4]}, which structure as shown in Figure 1.
The first layer is the input layer, the various scenario features and the return results of the stability state evolution characteristics in the evolution scenarios as the input quantities; The second layer is the fuzzy layer, which defines some fuzzy subsets of the input variables; The third layer is the fuzzy network inference layer, which is used to realize the mapping of the fuzzy value from the input variable to the output variable; The fourth layer is the quantization output layer, where the final result is the stampede level obtained by weighted average of inference mapping results of the third layer. This stampede level can directly reflect the stability of the crowd.

3. Analysis of scenario features and state evolution characteristics

In the large-scale crowd evacuation scenarios, the accuracy of the crowd stability study is affected by various evacuation scenario features and stability characteristics which are complex and numerous. The initial input variables of the intelligent evacuation model are scenario features. We can obtain the quantitative results of the main characteristics of the evacuated crowd through statistics and analysis. The table 1 briefly displays the characteristics of the evacuation scenarios and the evolution of the stability state.

| Scenario features                          | Stability State Evolution Characteristics |
|--------------------------------------------|-------------------------------------------|
| **Disaster Models:** Fire, Gas leak, Hurricane, etc. | Unstable Probability, Unstable Range |
| **Environmental Facilities:** Indoor, Outdoor, Transportation Hub, Obstacle Distribution, etc. | Stampede Probability |
| **Psychologic Features:** Nervousness, Panic, Excitement, Despair, Dementia, etc. | Evolution direction, mode, velocity |
| **Physiological and Social Characteristics:** Age, Gender, Disability, Flexibility, Weight, Strangeness, etc. | Evacuation Time |
| **Behavioral Characteristics:** Herd, Light, Homing, Unconventionality Action, etc. | Casualty rate |
4. Feature extraction and mapping network model

Based on the principle of the fuzzy neural network, this paper proposes feature extraction and mapping model for crowd evacuation scenarios and state evolution, where the structure is the same as the basic fuzzy neural network.

According to references [6-8], the input variables of the first layer are the main evacuation scenario features. Supposing its number is n, so the number of the first layer nodes is n too. And its input variables and output variables are set to: \( I_i^{(1)} = x_i, O_i^{(1)} = I_i^{(1)}, i = 1, 2, 3 \cdots, n \).

Where the first layer input is the crowd evacuation scenarios features of the natural language representation and the historical backtracking data of evacuation state evolution. The second layer is the fuzzy layer, and the Gaussian radial basis function is used as the fuzzy membership function. This layer consists of m neurons, divided into n groups, each group of k neurons, so \( m = n \times k \). Therefore, the input and output relationship of the \( j \)th neuron in the \( i \)th group is:

\[
\mu_j(x_i) = \frac{1}{\sqrt{2\pi\delta_j}} \exp \left( -\frac{(x_i - \theta_j)^2}{2\delta_j^2} \right)
\]

where \( \theta_j, \delta_j (i = 1, 2 \cdots, n; j = 1, 2 \cdots, k) \) indicate respectively the mean and variance of the \( j \)th feature in the \( i \)th group. \( \mu_j(x_i) \) indicates that the \( j \)th feature of the input sample belongs to the membership degree of \( Ci \) mode. The Output \( (y_{i1}, y_{i2}, \cdots, y_{ik})^T \) of the neurons in the \( i \)th \( (i = 1, 2 \cdots, n) \) group in the fuzzy layer constitutes the membership vector of \( Ci \) mode about the input sample. The k-dimensional eigenvectors are converted into membership degrees of each feature to the corresponding model in the fuzzy layer, the fuzzy processes of the input variables are completed. Therefore, the number of fuzzy network output rules of the second layer is \( m \times n \). Here we simplify the input and output relationships of the second layer to:

\[
I_i^{(2)} = O_i^{(1)}, O_i^{(2)} = \mu_j(x_i), i = 1, 2 \cdots, n; j = 1, 2 \cdots, k
\]

The third layer is the fuzzy neural network inference layer, and the transfer function of neurons is tansig. The hidden layer nodes are \( q \), and the input and output relationships of the nodes are:

\[
\begin{align*}
I_i^{(3)} &= s_j = \sum_{j=1}^{n} w_{ij}O_j^{(2)} - \theta_j \\
O_j^{(3)} &= f(s_j) = f(\sum_{j=1}^{n} w_{ij}O_j^{(2)} - \theta_j) \\
&i = 1, 2, 3, \cdots, m; j = 1, 2, 3, \cdots, q
\end{align*}
\]

where \( w_{ij} \) is the connection weight of the \( i \)th node from the second layer to the \( j \)th node of the third layer. \( \theta_j \) is the threshold of the \( j \)th node, and \( f(s) \) is a tansig function \([8]\).

The fourth layer is the output layer. The input variables of the fourth layer network are weighted average to obtain the final stamping level. The specific formula is as follows:

\[
\begin{align*}
I_i^{(4)} &= O_j^{(1)} = f(s_j) = f(\sum_{j=1}^{n} w_{ij}O_j^{(2)} - \theta_j) \\
y(x_i) &= \frac{\sum_{l=1}^{k} w_{il}I_i^{(4)}}{\sum_{l=1}^{q} w_{il}} \\
l = k = 1, 2, 3, \cdots, q; k = 1, 2, 3, \cdots, q
\end{align*}
\]
where \( w_j \) is the membership function of the input variables of the fourth layer, and \( y(x_i) \) is the event stamping level taking into account various of scenario features and state evolution characteristics.

5. Application Case

As a pilgrimage shrine, Mecca, Saudi Arabia attracts a large number of pilgrims every year, and crowded people often cause crowded stampede accidents. The Mecca stampede was particularly serious in 2015, which killed at least 2,177 people. This paper takes the Mecca stampede as the background, setting different street widths and different evacuation numbers as the input variables of the model simulation program. Then this paper performs multiple sets of experimental simulations to obtain multiple sets of result data, as shown in Figure 2, which is in line with the actual situation and proves the practicality of the network model.

![Figure 2. Simulation comparison results using the fuzzy neural network model](image)

6. Conclusion

In this paper, we propose feature extraction and mapping network model for crowd evacuation scenarios and state evolution using the principle of fuzzy neural network. Taking the evacuation scenario features as the first input of the neural network, using the adaptive and self-organizing learning ability of the fuzzy neural network, the weights and thresholds in the self-regulating network are obtained. Using the fuzzy layer and the inference layer of the fuzzy neural network to analyze the input factors intelligently, the final output of the network is crowd stampede level. With the self-learning ability of the novel network, we can obtain mechanism causes of instability and state evolution law of crowd evacuation, to intervene and guide the large-scale crowd evacuation.

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