Study on the location of building evacuation indicators based on eye tracking

Yue Li, Ping Zhang and Hui Zhang

March 18, 2018

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Yue Li
Institute of Public Safety Research
Department of Engineering Physics
Tsinghua University
Beijing 100084
China
yue-li15@mails.tsinghua.edu.cn

Ping Zhang
Institute of Public Safety Research
Department of Engineering Physics
Tsinghua University
Beijing 100084
China
zhangp14@mails.tsinghua.edu.cn

Hui Zhang
Institute of Public Safety Research
Department of Engineering Physics
Tsinghua University,
Beijing 100084
China
zhhui@tsinghua.edu.cn

ABSTRACT

Evacuation indicator is an important factor affecting evacuation efficiency during emergency evacuation. In order to study the relationship between the distribution of human's points of regard and evacuation indicators during building evacuation, this paper carried out two groups of building emergency evacuation experiments, to get the data of human's points of regard, one of the experimenters was selected to put on eye tracker during the experiment. This paper presents a method to preprocess the data of eye tracker and further analyzes the pretreatment results. The results show that evacuation indicators in different areas are suitable for different placement, which based on the position distribution of human's points of regard. For example, evacuation indicators in the corridor are suitable for higher placement, and evacuation indicators in the staircase are suitable for lower placement.

CCS CONCEPTS

• Design and analysis of algorithms→Mathematical optimization→Discrete optimization→Network optimization

KEYWORDS

building evacuation experiment; evacuation indicator; points of regard; eye tracking

1 INTRODUCTION

With the development of society and the growth of urban population, to meet the increasing demands of people's life, many large composite buildings have sprung up, and become common carriers of human activities. The increase of size and space, structure and function complexity of building, and the number of people inside the building，all of them will exacerbate the hazard of sudden events such as fires and terrorist attack, and will make it more difficult to evacuate safely. Evacuation indicator plays an important and irreplaceable role in rapidly evacuation, however with the increase of the complexity of the building, the evacuation indicators gradually expose a lot of problems.

The eye tracker is an eye-tracking device which was first used in psychological experiments. With the improvement of line-of-sight tracking technology, eye tracker is frequently utilized in diverse field. Zhang sen et al.[1] extended eye tracker's application into sports psychology, studied the psychological cognitive characteristics of athletes' decision-making; Li haiqiong et al[2] and Zhang jie et al.[3], utilized eye tracker to study the driver's viewpoint distribution to improve driving safety and traffic efficiency. Zhou xinyi[4] combined landscape of city parks and eye tracker to study the improvement of landscape design. At present, there are not many research on the combination of eye movement and evacuation. Weizhen[5] used eye tracker to study the mode of emergency evacuation of large stadium audience; Zhou Xueyan[6] utilized eye tracker to assist in improving the identification guidance of subway station, to enhance the mobile efficiency of crowd in the subway; Li lihua et al.[7] pioneered to use eye tracker in building evacuation experiments to study the individual and small group behavior in emergency.

To study rationality and improvement of the location of building evacuation indicator in different evacuation scenarios, this paper carried out the evacuation experiments in day-scenario and night-scenario, utilized eye tracker to collect data. Compared with traditional simulation, evacuation experiment can obtain human's relatively true psychology and behavior data in emergency; eye tracker is a common tool in psychological experiments which usually used to analyze the distribution of human's points of regard, the data obtained is quite accurate.

2 EXPERIMENT DESIGN

The experiment was conducted on April 26, 2017 at Liuqing Building of Tsinghua university. Liuqing Building has 11 floors, each of them is exactly the same structure, including 2 elevators and 2 staircases which are respectively located on eastern side and western side of the building, and the elevator is adjacent to the stairwell. The staircase totally has of 240 steps, each step is 120cm long, 15cm high, 30cm wide and 50cm long at the corner of the staircase. The first and second floor are 3.8 m high, and the

EM-GIS'17, November 7–10, 2017, Redondo Beach, CA, USA

ACM ISBN 978-1-4503-5493-6/17/11$15.00
https://doi.org/10.1145/3152465.3152467

third floor to 10th floor are 5.4 m high. Evacuation instructors are installed in the corridor and staircase of each floor. The structure diagram of Liuqing Building is shown in Fig 1.

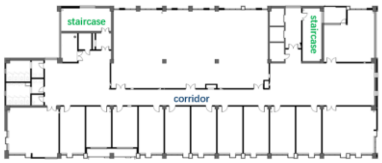

Figure 1: Structure Diagram of Liuqing Building of Tsinghua University

This experiment simulated the real evacuation scene, and the evacuation indicators are placed in different areas of each floor of Liuqing Building. Evacuation indicator is placed on one side of the wall in corridor and the height is close to the ground. Two kinds of signs are placed in the staircase, including floor number sign at each layer, evacuation indicator located at the corner of each floor and is highly close to the ground. Initially the subjects all gathered in a room on the 10th floor, when the alarm went off, the subjects were quickly evacuated from the room to the staircase, and then evacuated from the 10th floor to the first floor. One of the subjects was selected to wear eye tracker to record the eye movement.

All of the subjects are freshmen from Social Sciences of Tsinghua University. They are all the first time to come to Liuqing Building, and not familiar with its structure and evacuation route. In order to ensure the authenticity of the evacuation experiment, this paper only conducted an experiment respectively in the day and evening, so as to prevent the subjects from being too familiar with the construction structure. The start and end of the two experiments is the same, and so as the experimental route. In addition, the experiments adopt reward and punishment measures, the first person who arrives to the first floor will receive a monetary reward, and the person who arrives latest will deduct the money. The aim is to motivate the subjects to evacuate quickly, arouse the subjects' enthusiasm, and make the experiment closer to the real evacuation. The experiment scene is shown as Fig 2.

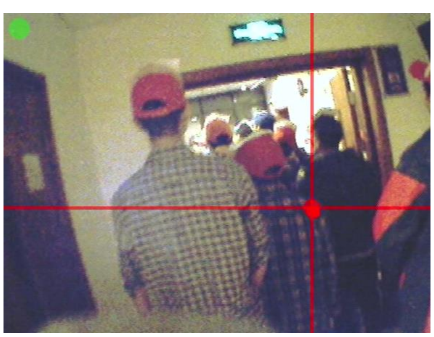

Figure 2: Emergency Evacuation Experiment

3 RELATED WORK

3.1 Human's Eye Movement

Information processing of human's eyes heavily rely on vision, about 80% to 90% of the external information is obtained through eyes. Eye tracker is an eye-tracking device based on the digital video, it's basic principle is to capture the eye image in real time by infrared camera of high frequency sampling, and then obtain eye movement data through image processing [5]. The concept and parameter index of human eye movement isn't consistent defined in many documentations, the following is the definition of high degree of recognition.

There are three main forms of eye movement: fixations, saccades and smooth pursuit. [6-15]

The fixation behaves as a stay on the observed target, the stay generally lasts at least 100ms. Human's eye is not absolutely stationary when fixing, the eyeball is constantly shaking slightly to see the object, its magnitude is generally less than 1 degree. Majority of the information is acquired and processed only when it is being watched. The point which gaze produces is called fixation point or point of regard.

The saccade is a rapid movement of the fixation point, and both eyes move simultaneously, the perspective is 1 to 40 degrees, the duration is 30ms to 120ms, the maximum speed is 400 degrees/s to 600 degrees/s. During the period of the saccades, the eyeball receives little information, because the image is moving too fast in the retina and the visual threshold is elevated as the saccade happens. This kind of point is called saccade point.

Smooth pursuit is a slow, binocular-moving eye movement form, the movement must have a slow moving target to be implemented. This kind of point is called unconscious point.

In addition, eye tracker also produces some noise points during the operation.

Therefore, the eye movement data collected by the eye tracker contain this four kinds of point: the fixation point, the saccade point, the unconscious point, and the noise point. Only the fixation points are valid data. The other three kinds don't contain valid information, they are collectively referred as the error points, and will be deleted by data preprocessing.

3.2 Eye Tracker's Original Data

The eye tracker brand used in this paper is Yarbus, its original data file includes the video file in mp4 format, and the detailed TXT file for each point which corresponds to the video file.

According to the eye tracker's specification, the eye tracker records data about every 1/30 seconds, the data of each record includes serial number, time, usage pattern, frame rate, eye observation point coordinates, pupil coordinates, and other data. The eye tracker includes two modes of operation, online and offline. Result shows that, there are slight fluctuations in the time of interval between the two points recorded in different modes, but it's roughly around 1/30 seconds.

Therefore, this paper makes a reasonable simplification as follows: define the data record interval of the Yarbus eye tracker as 1/30 seconds, show as t_{txt}.

According to 2.1, human's eye movement produces two fixations at least 0.1s, which is far larger than the time interval between the two data recorded by eye tracker. It can be deducted that the eye tracker not only records the fixation points, but also the saccade points, the unconscious points and the noise points. So it is needed to preprocess the eye tracker data, delete the error points, screen out the real points of regard, then analysis to improve the accuracy of experimental data.

3.3 Data Preprocessing

3.3.1 Analysis Process

This article gives the following definitions, define the time interval between two fixation points produced by human's eye movement as t_{por} ; define the time interval between two data recorded by eye tracker as t_{txt} ; define human's point of regard as dot_{por} ; define the data point recorded by eye tracker as dot_{txt} .

Due to the minimum value of t_{por} is 0.1s, and t_{txt} which values as 1/30 seconds didn't satisfy the definition of the fixation point, it can be calculated:

$$\frac{t_{\text{por}}}{t_{txt}} = 0.1 / \frac{1}{30} = 3 \qquad (1)$$

If the data is recorded every 1/30 seconds, so 0.1s is evenly divided into three equal parts. That is to say, the eye tracker record four data in 0.1s. Because t_{txt} is far less than t_{por} ,when the human eye movement is effective fixation, even though people are running during the evacuation, , the positions of dot_{por} points are almost unchanged in a very short period of 1/30 seconds. So, the four consecutive dot_{txt} points should be very close to each other in 0.1s.

Therefore, the method to determine whether a dot_{txt} point is the dot_{por} point is: determine whether the four consecutive dot_{txt} points which adjacent to each other in time are also closely adjacent to each other in position. If the answer is yes, they are regarded as dot_{por} ; if on the contrary, they're regarded as the error points needed to be eliminated.

The method to determine whether four consecutive points are closely adjacent is as below: calculate whether the four dot_{txt} points can be surrounded by an envelope circle whose radius is settled. The mathematical explanation is as shown in Fig 3: there are n points, the distance between dot i and dot i+1 is l_i , $1 \le i \le n-1$, r represents radius of the circle. When $r \ge \frac{1}{2}\sum_{i=1}^{n-1} l_i$, all the points can be surrounded in the circle.

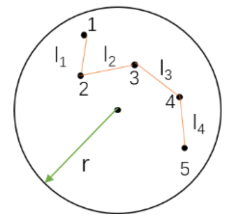

Figure 3: The Envelope Circle Diagram Including n Points

3.3.2 Related Equation

This paper defined: the effective length of video is T, per frame time of the video is Δt , frame number is $n = \left[\frac{T}{\Delta t}\right]$, radius of the envelope circle is $r \ge \frac{1}{2}\sum_{i=1}^{n-1} l_i$, the coordinate of dot_{txt} point is $\left(x_i, y_i\right)$, the coordinate of dot_{por} point is $\left(Z_{xi}, Z_{yi}\right)$.

When the radius of envelope circle meets the following condition, it is considered that four eye tracking points are points of regard.

$$r \ge \frac{1}{2} \sum_{i=1}^{\left[\frac{T}{\Delta t}\right]-1} \sqrt{\left(x_{i+1}-x_i\right)^2 + \left(y_{i+1}-y_i\right)^2} \qquad (2)$$

If the four consecutive dot_{txt} points are found, because the time differences and position differences among these four points are very small, the arithmetic mean value of their coordinate is regarded as the coordinate of dot_{por} point which is shown as $\left(Z_{xi}, Z_{yi}\right)$.

$$Z_{xi} = \frac{1}{4}\sum_{i=1}^{i+4} \mathrm{x}_i \qquad (3)$$

$$Z_{yi} = \frac{1}{4}\sum_{i=1}^{i+4} y_i \qquad (4)$$

4 POINT OF REGARD ANALYSIS

In order to get the distribution of the dot_{por} points, this paper performs a series of preprocessing towards the obtained data. For the determination of envelope radius size, the radius was determined to be 6 based on repeated analysis and comparison. The dot_{por} points distribution of the two experiments are shown in Fig 4 and Fig 5.

Figure 4: Points of Regard Distribution In Day-scenario Experiment

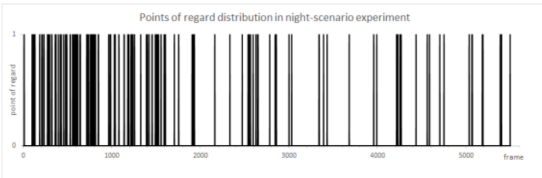

Figure 5: Points of Regard Distribution In Night-scenario Experiment

The experiments on day and night were both evacuated from the 10th floor to the 1st floor, whose routes are consistent and the evacuation time are close. The number of data points recorded by eye tracker is 5000 and 5500 respectively, the number of dot_{por} points after data preprocessing are 153 and 210 respectively. Among them, when the evacuation indicator and dot_{por} point are appearing in the same screen, the number is 61 and 83 respectively. The preprocessing results are shown in table 1.

Table 1: The Preprocessing Results

	dot_{txt}	dot_{por}	dot_{por} point is in the same frame with evacuation indicator
Day	5000	153	63
Night	5500	210	83

A further analysis was made on the dot_{por} points through preprocessing. Find out the corresponding image data for each dot_{por} point, select the image which contains both dot_{por} point and evacuation indicator. The image data are distributed in different areas of the building, including corridor and staircase. There are only evacuation signs in the corridor, and in the stairwell there are both floor number signs and evacuation signs. Process every picture by adding a 13 by 18 grid to make the scene as delicate as possible, as Fig 6 shows.

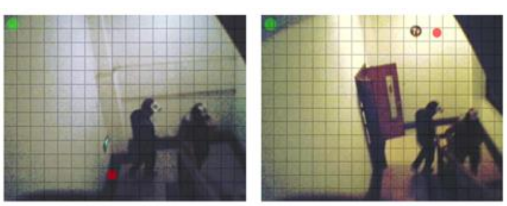

Figure 6: Image Data By Grid Processing

According to the statistics, the relative position distribution between dot_{por} point and evacuation indicator at different location is shown in table 2.

Table 2: Relative Position Distribution Between dot_{por} Point And Evacuation Indicator In Different Area

Scene	the relative position of dot_{por} point with evacuation indicator	evacuation indicator in corridor	floor number sign in staircase	evacuation indicator in staircase
Day	top	34	0	0
	middle	5	5	0
	bottom	0	15	4
Night	top	40	0	1
	middle	19	1	5
	bottom	1	7	5

It can be concluded that: the evacuation signs in the corridor are usually placed near the low level of the ground, this is because the smoke is heating up when fire happens, and people are more likely to bend down to see the signs; however, the results show that, when people are evacuated in the corridor, most of the people's points of regard are higher than the evacuation indicator no matter day or night. Therefore, it is recommended to increase evacuation indicators at high place in the corridor. The improvement is applicable to emergency evacuation in smokeless conditions such as earthquake, terrorist attacks. On the contrary, when people are evacuated in the stairwell, their points of regard are mostly lower than the floor number sign as well as evacuation indicator, there is a close relationship with person often focuses most of his or her attention on the feet when goes down the stairs. Therefore, it is suggested that the indication position of the stairsshall be pasted on the floor of the stairwell at the evacuation floor and ground floor.

5. CONCLUSIONS

This paper adopts the method of emergency evacuation experiment, utilizes eye tracker as the experimental instrument to obtain authentic and credible data; selects the fixation point based on the moving range of human's points of regard in the unit time, and presents a new approach to the data of eye tracker. The experimental result verifies the distribution of the points of regard during emergency evacuation, studies the rationality of location distribution of the existing building evacuation indicators. The result shows that the location distribution is a bit reasonable, there is still space for improvement, for example, it is recommended to increase the evacuation indicators at the high place of the corridor for smokeless conditions; but inside the stairwell, floor number signs and evacuation instructions should be moved down; and mark floor information on the refuge floor and the ground floor.

However, the current method of data analysis is relatively rough and qualitative; the preprocessing method is limited to the eye tracker brand used in the experiment, it could only provide a train of thought about data processing which is lacking of universality. The next step is to refine the data processing method, it is recommended to combine Microsoft's new HoloLens with eye tracker, to build a three-dimensional model of the building, record each point of regard in the three-dimensional model intuitively, and make a massive census. This method is more accurate and quantitative.

A HEADINGS IN APPENDICES

The rules about hierarchical headings discussed above for the body of the article are di.erent in the appendices. In the appendix environment, the command section is used to indicate the start of each Appendix, with alphabetic order designation (i.e., the first is A, the second B, etc.) and a title (if you include one). So, if you need hierarchical structure within an Appendix, start with subsection as the highest level. Here is an outline of the body of this document in Appendix-appropriate form:

A.1 Introduction

A.2 Experiment Design

A.3 Related Work

A.3.1 Human's Eye Movement

A.3.2 Eye Tracker's Original Data

A.3.3 Data Preprocessing

A.3.3.1 Analysis Process

A.3.3.2 Related Equation

A.4 Point of Regard Analysis

A.5 Conclusions

A.6 Acknowledgments

A.7 References

ACKNOWLEDGMENTS

The research is partially funded by the National Natural Science Foundation of China (Grant No.91646201).

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