Fuzzy Judgment of Step Slip Throw Based On Entropy Factor and Life Factor

Hui-Min CHEN\textsuperscript{1,2}, Yong-Zhen ZHANG\textsuperscript{2,a} and De-Qiang CHEN\textsuperscript{2}

\textsuperscript{1}Wuhan Research Institute of Materials Protect, China Academy of Machinery Science and Technology, Wuhan, Hubei, PR China
\textsuperscript{2}Key Laboratory of Materials Tribology, Henan University of Science and Technology, Luoyang, Henan, PR China

Abstract. In order to obtain the complex relationship between the human body step slip and the various factors, it is necessary to accurately identify the main influencing factors of step slip. Based on fuzzy mathematics and information entropy theory, a method of step slip fuzzy judgment based on fuzzy information entropy fusion life factor is proposed. Through the establishment of mathematical model integrating information entropy with life factor fuzzy judgment, the quantitative analysis is combined with expert experience and qualitative analysis. Using the test platform with six degrees of freedom are tested under various influencing factors the actual friction coefficient, combining the objective weights determined by the test data with the subjective weights determined by the common sense of life, improve the scientific weight determination. The results show that the fuzzy judgment model established in this paper is feasible and effective for judging the main reasons of step slip.

1 Introduction

Many factors can cause the body to slip or fall down when walking, including walking speed, step length, acceleration, outsole material, uphill, downhill, and contains a variety of uncertainties, randomness and fuzziness [1-3]. So the factors of uncertainty and processing become the key to determine whether can fall. In the process of comprehensive judgment of step slip throw factors, the determination of the weight of each factor is a crucial issue [4-6]. The typical methods of determining weights include Delphi method, expert scoring method, entropy weight method, cluster analysis method, analytic hierarchy process, etc. [7]. However, each of these methods has its disadvantages. Such as Delphi method, expert scoring method and so on, the results of its empowerment depend on the will of experts, inevitably affected by the subjective factors of experts. The entropy weight method and the main analytic hierarchy process are based on objective data, and the weighted results may not coincide with the actual situation. As one of the most commonly used methods for comprehensive evaluation of complex systems, analytic hierarchy process (AHP) has some problems, such as the consistency between judgment and matrix, the difficulty of consistency test [8]. Other literatures mainly focus on the influence of single factor on the step slip fall, which is obviously not consistent with the actual situation [9-10].

According to the theory, the slip is determined according to whether the actual friction coefficient is greater than the static friction coefficient, and when the actual friction coefficient is greater than the static friction coefficient, the slip phenomenon occurs. Therefore, according to the actual life presents a multi factor entropy factor fusion experience factor of step sliding fall comprehensive judgment method, the objective data and life experience combined with the comprehensive consideration of all factors to determine the weights of factors, and then comprehensive judgment step sliding fall.

2 Modelling and Analysis of Step Slip Fall Based On Fuzzy Factor and Life Factor Fuzzy Judgment

Since the American mathematician Shannon put forward the concept of entropy, to solve the problem of information measurement has played a great role. For the general definition of entropy, suppose $M$ is a measure Lebesgue space of $\mathcal{B}$ algebraic sets generated by $H$, with measure $\mu$, and space $M$ can be expressed as the finite partition of $\mathcal{B}$ into incompatible sets, namely:

$$M = \bigcup_{i=1}^{n} (A_i), \quad A_i \cap A_j, \quad \forall i \neq j$$

the information entropy for the division of $A$:

$$S(A) = -\sum_{i=1}^{n} \mu(A_i) \log_2 \mu(A_i)$$  \hspace{1cm} (1)$$

where, $\mu(A_i)$ as a set of measure $i = 1, 2, \ldots, n$.

The information entropy is the characterization of many uncertain factors. If the degree of confusion, disorder, randomness is larger, the system of information entropy is higher; on the contrary, if a system is determined, to comply with certain rules, obey a certain
order, the information entropy corresponds to the smaller the system. In addition, the information entropy is calculated from the original data, so the objectivity of the measurement of the system uncertainty is higher.

Entropy, as a measure of uncertainty, can be expressed formula (2), where \( p_i \) represents the probability of the system in the corresponding state,

\[
H(p_1, p_2, \cdots, p_n) = -k \sum_{i=1}^{n} p_i \log_2 p_i
\]  

(2)

When entropy satisfies (3),

\[
\begin{align*}
H(p_1, p_2, \cdots, p_n) &= H(1/n, 1/n, \cdots, 1/n) \\
H(p_1, p_2, \cdots, p_n) &= H(p_1, p_2, \cdots, p_n, 0) \\
H(AB) &= H(A) + H(B/A)
\end{align*}
\]  

(3)

With unique form,

\[
H(p_1, p_2, \cdots, p_n) = -\sum_{i=1}^{n} p_i \log_2 p_i
\]  

(4)

Let \( A \) be a non-fuzzy judgement matrix,

\[
A = \begin{pmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
a_{21} & a_{22} & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & a_{nn}
\end{pmatrix}
\]  

(5)

Let \( s_{kj} \) be the elements of the matrix \( K \) and \( f_{kj} \) be the sum of the elements of row \( k \) in the matrix \( A \), and \( p_{kj} = a_{kj}/s_{kj} \) is the probability of the occurrence of the \( j \) element in line \( k \). Thus entropy is obtained.

\[
H_i = -\sum_{j=1}^{n} f_{ij} \log_2 f_{ij}
\]  

(6)

Normalized, \( H_i \) is the entropy factor.

In the actual slip fall in the comprehensive evaluation, the effect of the sliding friction coefficient matrix fall factor can be \( R \). If factor \( U_i \) support for the evaluation of each index of concentrated \( p_{ij} \) greater, the factor in comprehensive evaluation of plays the role greater. If the degrees of support all are equal, i.e. expert assessment results are too scattered, poor cohesion, the evaluation of this factor is almost useless in the comprehensive evaluation.

By the extreme of entropy, \( p_{ij} \) is nearly equal, the entropy is greater. So the factors of comprehensive evaluation system of uncertainty are greater. Therefore, on the basis of various factors on the evaluation indexes of centralized support \( p_{ij} \) the weight of every factor was computed using information entropy. The relative importance of factors of \( U_i \) by the entropy to measure the following:

\[
H_i = -\sum_{j=1}^{m} p_{ij} \ln p_{ij}
\]  

(7)

In the formula (7), the closer the \( p_{ij} (j = 1, 2, \cdots, m) \) is, the greater the entropy is. When the value of \( p_{ij} \) is equal, the maximum entropy is \( H_{\text{max}} = \ln m \). The relative importance entropy of factor \( I \) is the formula (8) by normalizing the formula (7) with \( H_{\text{max}} \):

\[
e_i = \frac{1}{\ln m} \sum_{j=1}^{m} p_{ij} \ln p_{ij}
\]  

(8)

In the formula (8), when the value of \( p_{ij} (j = 1, 2, \cdots, m) \) is equal, the maximum value of \( e_i \) is 1, that is to say, the value of \( e_i \) satisfies \( 0 \leq e_i \leq 1 \). When the entropy is the maximum, this factor has the least contribution to the comprehensive evaluation of the system, so \( 1 - e_i \) can be used to measure the weight of the factor \( U_i \). The weighted \( \phi_i \) of the risk factor \( U_i \) is obtained by normalization.

\[
\phi_i = \frac{1}{n-\sum_{i=1}^{n} e_i} (1 - e_i)
\]  

(9)

3 Comprehensive Judgment Methods of Entropy Factor and Life Experience Factor Influencing Sliding Throw

According to the basic condition of human body slipping, comprehensive weight \( \omega \) of influencing factors fell slide consists of two parts. One is the objective weight \( \phi_1 \) mining from the experimental data. The second is the subjective weight \( \phi_2 \) determined by the experience of life.

\[
\omega = (1 - \alpha)\phi_1 + \alpha\phi_2
\]  

(10)

Where, \( \alpha \) is the life experience factor, \( 0 \leq \alpha \leq 1 \), the preference of experts to reflect the subjective and objective weights. If \( \alpha \) is bigger, experts believe that the common sense of life more important. If \( \alpha \) is smaller, it shows that the experts believe the test data.

Based on the impact factors of slip, entropy factor and life experience, weight is determined as follows:

1 According to the experiment, the friction coefficient matrix \( \rho_k \) of each slide impact factor is obtained.

2 According to the formula of relative importance (7), the relative importance entropy \( e_i \) of each factor is calculated.

3 According to the formula (8), the entropy \( e_i \) of Step 2 is normalized to obtain the objective weight \( \phi_i \) of each index.

4 The experts give the subjective weight \( \phi_2 \) of each index in the index system according to the experience knowledge.

5 According to the preference of decision maker, the appropriate empirical factor \( \alpha \) is selected to calculate the comprehensive weight set \( W \) of the index.

So far, the influence of various factors on sliding fall can be comprehensively evaluated:

Firstly, the influence factor sets \( U \) and evaluation sets \( V \) are constructed to evaluate the slide throw synthetically. The factors including walking speed, step length, acceleration, on the downhill or uphill, shoe prints, and other factors affect the slip fall. The judgment
set is a set of results that result in slip. This paper is divided into two situations: safety and danger.

Secondly, according to the judgment set \( V \), the judgment matrix is determined according to the experiment. Through the orthogonal experiment, the single factor is judged and the fuzzy set \( R_i = (r_{i1}, r_{i2}, \cdots, r_{im}) \) on the judgment set is obtained. Where, which \( r_{ij} \) represents the membership degree of the factor \( v_i \) to the \( v_j \) of the judgment set, thus the membership degree matrix \( R = (r_{ij})_{n \times m} \) is obtained.

Thirdly, fuzzy comprehensive is evaluated. The weight set \( W \) of each factor is determined by the weight determination method based on entropy factor and life experience coefficient proposed in this paper. And the judgment matrix \( B = W \circ R \) is synthesized, and there “\( \circ \)” is the fuzzy synthesis operator.

Finally, the judgment of the evaluation results is given. The final vector \( B \) obtained by multi-level fuzzy comprehensive evaluation is used to judge the result of slipping.

4 The Friction Coefficient is obtained by Experiments

According to the previous analysis, the occurrence of sliding fall is related to all the above factors, but to a point, it can be judged by the critical friction coefficient when slipping occurs. As the friction coefficient changes in the course of human walking, slip occurs when the dynamic friction coefficient is greater than the critical friction.

In order to verify the correctness of the above theory, tests are carried out on a six degree of freedom test platform with two measuring plates of left and right feet, as shown in Figure 1.

![Figure 1. Six degree of freedom test platform.](image)

When walking, the foot force analysis is shown in figure 2.

The test plan is as follows:
1. Different factors about walking speed, step length, acceleration, downhill or uphill, sole pattern, men and women were tested separately.

<table>
<thead>
<tr>
<th>Results</th>
<th>Results</th>
<th>Results</th>
<th>Results</th>
<th>Results</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed(m/s)</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.4</td>
<td>0.38</td>
<td>0.38</td>
<td>0.37</td>
<td>0.36</td>
</tr>
<tr>
<td>Step length(m)</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.28</td>
<td>0.288</td>
<td>0.31</td>
<td>0.37</td>
<td>0.41</td>
</tr>
<tr>
<td>Acceleration (m/s²)</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.19</td>
<td>0.2083</td>
<td>0.2206</td>
<td>0.2435</td>
<td>0.30</td>
</tr>
<tr>
<td>Uphill(°)</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.20</td>
<td>0.1320</td>
<td>0.1298</td>
<td>0.16</td>
<td>0.2507</td>
</tr>
<tr>
<td>Downhill(°)</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.20</td>
<td>0.3285</td>
<td>0.4123</td>
<td>0.4315</td>
<td>0.4738</td>
</tr>
<tr>
<td>Sole pattern</td>
<td>Transverse stripe</td>
<td>Vertical stripe</td>
<td>Polygonal lines stripe</td>
<td>Dot pattern</td>
<td>Diamond pattern</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.26</td>
<td>0.22</td>
<td>0.29</td>
<td>0.25</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Note: The test friction coefficient is the maximum friction coefficient when the foot follows the ground.
5 Calculations and Analysis of Fuzzy Judgement of Step Slip Throw

First, the construction step slip factor set \( U = \{ \text{step, pace, acceleration, uphill, downhill, shoebotten} \} \), slip fall possibility evaluation set can be set 2 level, \( V = \{ \text{safety, risk} \} \).

Secondly, a number of experts in related fields are invited to evaluate the influence degree of each influencing factor according to the experimental data and life experience, and the evaluation matrix is as follows.

\[
R = \begin{bmatrix}
0.6 & 0.4 \\
0.5 & 0.5 \\
0.8 & 0.2 \\
0.6 & 0.6 \\
0.7 & 0.3 \\
0.5 & 0.5 \\
\end{bmatrix}
\]

Then, according to the test data, the weight of each influence factor is calculated according to the membership matrix. Objective weight is obtained \( \hat{\phi}_1 = (0.162, 0.123, 0.277, 0.065, 0.268, 0.105) \), set \( a = 0.2 \). The subjective weight of the expert \( \phi_2 = (0.12, 0.08, 0.3, 0.15, 0.25, 0.10) \). According to fuzzy composition operation \( B = W \circ R \), so \( B = (0.154, 0.114, 0.282, 0.082, 0.264, 0.104) \).

Finally, according to the maximum membership criterion, it can be concluded that the influence factors of the test can’t cause the possibility of slipping. It can be seen from the third and fifth data that it is obviously easier to cause slipping when walking on the downhill slope and the acceleration of the platform which is equivalent to the acceleration of the human being.

Conclusions

There is a great deal of uncertainty in the judgment of human walking slip and fall, because of the many factors involved, and the result of the comprehensive influence of various factors. In this paper, a fuzzy comprehensive sliding throw method based on entropy factor and life experience factor is proposed. The use of fuzzy sets to represent life experience knowledge, to the greatest extent, retains and reflects the reality of life, but does not lose the authenticity of the experimental data. The weights are determined by the method of entropy fusion weight factor and factor based on the experience of life, combining the objective weight with subjective weight, the realization of the unity of subjective and objective, improve the scientific evaluation of the results of human walking slip fall.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant Nos. 51175149, 51405134 and 51375147). The authors wish to thank our colleagues for their assistance during the course of this study.