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Article

Biomechanical analysis and application of image processing technology based on deep learning in the indoor evaluation system of high-rise buildings

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Abstract: In the context of biomechanics and the built environment, understanding the relationship between the indoor space layout of high-rise buildings and human biomechanical responses is crucial. To enhance the quality of the indoor space layout of buildings with respect to human biomechanical comfort and functionality, this paper proposes a method for extracting the characteristics of the indoor space layout of high-rise buildings based on deep-learning image processing. The indoor space layout parameters are not only related to architectural aesthetics but also have implications for human movement and biomechanical behavior. For example, the dimensions and configurations of rooms and corridors can affect gait patterns, body postures, and muscle activations during walking and other activities. According to the extracted indoor space layout parameters, their edge sequences are determined. The image processing algorithm based on deep learning is then used to control the convergence of the characteristic parameters. This process is not only for architectural feature extraction but also to analyze how these features interact with human biomechanics. For instance, the angles and lengths of corridors can influence the turning radii and step frequencies of individuals, which are key biomechanical factors. By extracting the characteristics of the indoor space layout of high-rise buildings, we can evaluate how well the space accommodates human movement and biomechanical needs. The results reveal that the proposed method can effectively extract features relevant to both architecture and biomechanics, and the accuracy in assessing biomechanically relevant features is always higher than 90%. This high accuracy indicates the potential of this method to contribute to the design of indoor spaces that are more conducive to human biomechanical well-being and efficient movement.

Keywords: image processing; high-rise buildings; indoor; deep learning; biomechanical analysis

Image feature extraction is a key step. Traditional image processing methods often rely on manual design of features, while deep learning technology can automatically extract rich feature information from images. For example, convolutional neural network (CNN), as a typical deep learning model, performs well in image feature extraction. Through training, CNN can automatically learn the texture, color, shape and other features in the image, providing strong support for subsequent indoor evaluation. Image segmentation and object detection is another important step. Deep learning techniques have also made breakthroughs in this area. For example, semantic segmentation technology based on deep learning can accurately segment different objects in indoor scenes, providing a basis for subsequent indoor evaluation. At the same time, object detection technology can detect key targets in indoor scenes, such as people, furniture, etc., which helps to improve the accuracy of indoor evaluation. Moreover, deep learning technology can enhance and denoise images to improve image quality. For example, the image denoising algorithm based on deep learning can effectively remove the noise in the image and improve the image clarity.

In this paper, the internal structure of modern urban housing is analyzed and analyzed. In this project, visual identification technology is combined with visual parameter characteristics to establish a set of analytical models for the internal structure and functional characteristics of high-rise buildings. Through the analysis of its internal structure, its internal structure design level can be effectively improved [1]. Because the internal structure of high-rise buildings is becoming more and more complex, the higher demand for its internal space layout is put forward. For this reason, domestic and foreign scholars have done a lot of research on its internal structure and obtained some successful experience.

Therefore, this project intends to use deep neural network technology to study the feature extraction problem of the internal spatial layout of high-rise buildings. Firstly, an image-based multi-resolution image extraction method is established. Secondly, the visualization image of the internal structure of the high-rise building based on video is combined with the depth image analysis. On this basis, the visual characteristics of the internal structure of the high-rise building are extracted by linear filter and analyzed. Then, it is analyzed by using deep neural network, and a series of indoor spatial distribution characteristics are obtained.

1. Visual image acquisition of indoor space layout of high-rise buildings

In this paper, a visual identification model of interior spatial layout of high-rise buildings based on super-resolution and multi-parameter is established, and its modeling and analysis are carried out. **Figure 1** is a step used to calculate the internal spatial parameters of a tall building.

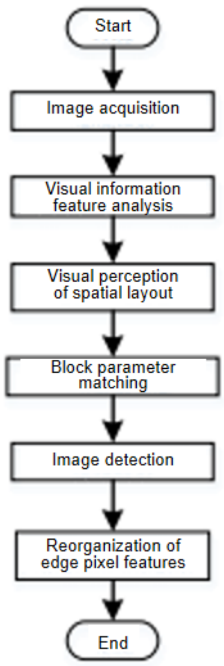

Figure 1. Extraction process of indoor space layout parameters of high-rise buildings.

As shown in **Figure 1**, in the process of extracting spatial parameters inside high-rise buildings, visual images are acquired first, and then the characteristics of visual information are analyzed. The visual image points of the interior space layout of high-rise buildings are established. Secondly, the interior spatial layout model of high-rise building based on visual characteristic parameters is constructed. Then, the block image detection algorithm [2] of multi-dimensional visual space is used to match the parameters of each block, so as to realize the image detection. On this basis, a method for estimating the boundary feature quantity of visualized images of interior spatial layout of tall buildings is proposed.

$$yh_r = ku(c) + bv(t). \tag{1}$$

That is to reconstruct the boundary pixels. Where, yh_r is the value of image boundary pixels arranged inside high-rise buildings. $ku(c)$ is a kind of inner space image in the interior space arrangement with the central edge as the core. $bv(t)$ refers to the value of the partition calculation of the overall spatial layout effect of the high-rise building.

The visualization image of the internal structure of high-rise buildings contains a large number of pixels, so it is necessary to integrate them deeply. Based on $R([a,b],c)$ and $T([a,b],c)$, a pixel fusion model which can reflect the visualization image of the interior layout of high-rise buildings [3] is established.

$$E_i = RT \tag{2}$$

Based on the pixel fusion basis, the visual fusion characteristic quantity of the indoor space layout of high-rise buildings is set as $E([a,b],c)$; $D([a,b],c)$ is the image frame sequence. Using the filter shown in **Figure 2**, the filtering processing of the visual pixels of the indoor space layout of high-rise buildings is realized.

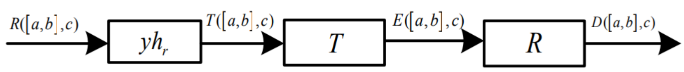

Figure 2. Filtering processing of visual pixels of indoor space layout of high-rise buildings.

Acquisition of feature quantities of indoor space layout of high-rise buildings

Based on the collection and preprocessing of the visual image pixels of the indoor space of high-rise buildings, it is necessary to obtain the extracted spatial layout feature quantities to extract the features of the indoor space layout of high-rise buildings [4].

A degradation feature evolution analysis model of the visual image of the indoor space layout of high-rise buildings is constructed by using the edge parameter distributed detection method [5], and then the parameter distribution sequence of the indoor space layout of high-rise buildings is obtained, as follows:

$$k(p) = k(p\Delta t), p \geq 0 \tag{3}$$

where Δt is the period of time over which visual information is sampled. Where, P is a group of visual characteristics used to describe the internal spatial arrangement of high-rise buildings. Let b^{er} be the standardized parameter of the visual image $(a^w, a^m, a^n)$of the internal structure of high-rise buildings in the distribution domain, and $f=(1,2,3,\cdots,n)$ is the color parameter of the visual image of the internal structure of high-rise buildings, then the visual characteristic components of the internal structure of high-rise buildings can be obtained, as follows:

$$G^r = k(p\Delta t) + (fa^w + fa^m + fa^n)^2 \tag{4}$$

The high-order moment [6] in the fuzzy feature distribution area of the visual image of the indoor space layout of high-rise buildings is:

$$cHc = \frac{1-k(p\Delta t)}{\cos^{-1} A + \sin^{-1} B} \tag{5}$$

where,

$$A = \frac{k(p)}{2\pi}\sin(k(p\Delta t)^2) + (fa^w + fa^m + fa^n)^2 \tag{6}$$

$$B = \frac{k(p)}{2\pi}\cos(k(p\Delta t)^2) + (fa^w + fa^m + fa^n)^2 \tag{7}$$

By using the high-resolution multi-dimensional space block combination method, the visual distribution pixel set of the indoor space layout of high-rise buildings is obtained as follows.

$$R_r(f) = \frac{G^r + v^r}{k(p\Delta t)}, v^r = 1,2,3,\cdots,n \tag{8}$$

In this paper, the visual image of the interior space layout of high-rise buildings is analyzed by the method of first and second parameterization. On this basis, according to the characteristics of the hierarchical layout embodied by each characteristic parameter, a criterion function of the internal space layout of high-rise buildings based on visual fusion is proposed.

$$ret_c = R_r(b) - \cos^{-1} A. \tag{9}$$

Then, the feature map is used to visualize the internal structure of the high-rise building and obtain its feature quantity.

2. Edge parameter extraction of parameter distribution sequence of indoor space layout of high-rise buildings

On the basis of the characteristic information of the internal structure of the high-rise building, the integrated extraction is carried out by combining the process deep learning method [7].

Supposing the indoor visual feature extraction parameter of high-rise buildings isnsp, and the linear unbiased estimated value is$\hat{z}(s_0)$,then the best criterion for sparse feature decomposition of the visual image of the indoor space layout of high-rise buildings meets the following formulas:

$$Jr = \hat{z}(s_0)(ret_c + ret_b)^2 + nsp, \tag{10}$$

$$C_{rt} = Jr + \frac{nsp}{ret_c + ret_b} \tag{11}$$

$$Lr = \begin{cases} log(Jr + v), & v \neq 0 \\ log(Jr - v), & v \geq 2 \end{cases} \tag{12}$$

where *Lr* represents the scale information of the multi-dimensional space block image; C_n represents the degree of sparseness value of the multi-dimensional space image feature quantity.

On this basis, the fuzzy state parameter of the indoor space layout feature of high-rise buildings is set as:

$$A_{cd} = Jr - \frac{nsp\left(ret_c + ret_b\right)}{C_{rt} + l} \tag{13}$$

Using the fast Fourier transform method [8], the dynamic contour distribution feature points of the visual image of the indoor space layout of high-rise buildings are reconstructed, and the output gradient information of the visual image of the indoor space layout of high-rise buildings is calculated [9]. The obtained output value is:

$$B_{cd} = Jr + \frac{nsp(ret_c + ret_b)^2}{(C_{rt} + l)^2} \tag{14}$$

Through edge parameter segmentation and fusion filtering detection, the method of constructing a constraint model is employed to obtain the visual resolution parameter of the indoor space layout of high-rise buildings, as follows:

$$We = gi\left(xt + xp^2\right) - gi(xt - xc) \tag{15}$$

where xt, xp^2, xc are the interval parameters of the spatial layout visual image of the visual information component of the indoor space layout of high-rise buildings. Based on this, the edge parameter of the parameter distribution sequence of the indoor space layout of high-rise buildings can be obtained, as follows:

$$tui\left(h_1 + h_2\right) = gi\left(\frac{xt + xp^2 + xc}{l}\right) \tag{16}$$

where gi is the edge value of the parameter distribution sequence of the indoor space layout of high-rise buildings.

Image processing based on deep learning for indoor space layout of high-rise buildings

Aiming at the problem of extracting internal structural characteristics of high-rise buildings, a method based on multiple influence factors is proposed [10,11]. Therefore, this project intends to use deep learning technology to optimize the model and achieve effective regulation of model parameter convergence, so as to achieve accurate acquisition of indoor layout characteristics [12]. Deep neural network is a new intelligent computing method which has arisen in recent years [13]. This method combines genetic algorithm with genetic algorithm to form a new intelligent optimization method [14,15]. The algorithm has a fast-solving speed, and the optimal solution can overcome some difficulties in the current research. Therefore, this project intends to use deep neural network method to analyze the internal structure of high-rise buildings.

On this basis, the convergence threshold of the deep neural network is set, and the formula is as follows.

$$tui\left(h_1+h_2\right)+y(\vec{x})=0, y\neq 0 \tag{17}$$

where $(\vec{x})$ is the gray-scale pixel information of the visual component of the indoor space layout of high-rise buildings.

On this basis, a high precision image processing method based on image processing technology is proposed. The formula for division is:

$$fg^i = qr + \frac{xcv}{vrt} \tag{18}$$

where, qr is the resolution used to extract the visual features of the spatial layout inside the high-rise building. Where, xcv is the time interval parameter of the data block, and vrt is the information entropy used for feature extraction.

By using the method of two dimensions parameter fitting, $j=\{jl, l\in 3\}$ set of fitting results from the multi-dimensional space block image are obtained. In a single pixel value distribution area $j=\{jl, l\in 3\}$, the visual features of the internal spatial layout of high-rise buildings are segmented at multiple levels to obtain the multi-layer feature information of the interior layout.

$$K^{im} = i(nc+nb)+j(nm-nr). \tag{19}$$

On this basis, based on the multi-scale learning method, the visualization image of the internal structure of the high-rise building is reconstructed. Among them, 4 (nc, nb, nm, nr) represents multiple levels of multiple levels extracted from multiple levels, where y^e, y^r represents multiple levels of multiple levels. On this basis, by analyzing the constrained parameters of the restored image and fusing the background values of the image, the following conclusions are obtained:

$$CB^{re} = \frac{K^{im}\left(y^e+y^r\right)}{fg^i}+qr+\frac{xcv}{vrt}.$$

A series of fuzzy distribution sets are constructed by selecting a series of proximity functions, and the interior layout of high-rise buildings is visually analyzed [14]. Based on the reuse of middle-level functions, this paper obtains the boundary characteristic quantity of visual characteristics of the internal structure of high-rise buildings.

$$SDR = \frac{xy}{CB^{re}}, \tag{21}$$

$$T_i(g_i) = \frac{2\pi(go^i + gu^i)}{SDR} \tag{22}$$

Among them, m is used to extract the resolution of visual features of the internal layout of high-rise buildings, and n is used to represent information entropy [15].

On this basis, a feature extraction method of interior layout of high-rise buildings based on deep neural network is proposed. **Figure 3** shows the flow of this execution.

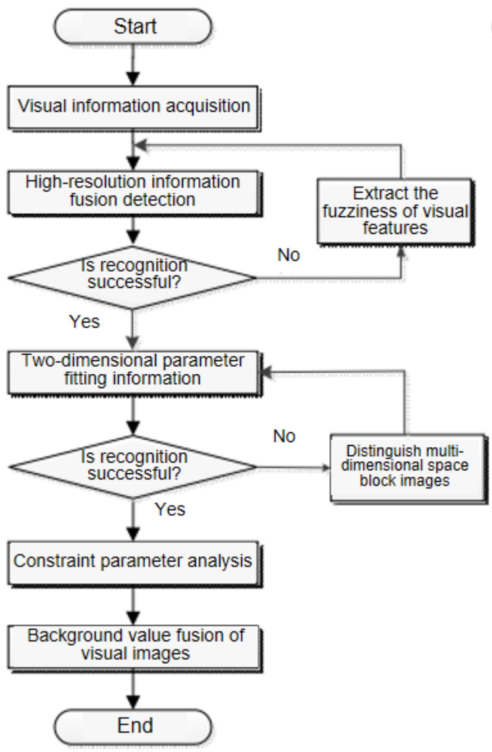

Figure 3. Feature extraction implementation of image processing based on deep learning.

3. Experimental analysis

3.1. Experimental scheme

The experimental results show that the proposed algorithm is effective. This paper takes WINDOWS10 as the operating system and uses MATLAB language to write the simulation software. The parameters for the test environment are shown in **Table 1**.

Table 1. Experimental parameter settings.

Test number	Pixel intensity/dB	Visual fusion difference	Feature recognition degree/%
1	19.6825	5.5522	75.5000
2	20.761 9	5.8567	68.8333
3	19.4286	5.4806	69.6667
4	21.1429	5.9642	71.1667
5	18.9206	5.3373	72.1667

Table 1. (*Continued*).

Test number	Pixel intensity/dB	Visual fusion difference	Feature recognition degree/%
6	19.1746	5.4090	68.3333
7	18.222 2	5.1403	74.0000
8	18.7302	5.2836	72.0000
9	19.3651	5.4627	64.1667
10	18.1587	5.1224	69.6667
11	17.6508	4.9791	71.5000
12	17.269 8	4.8716	69.6667
13	17.8413	5.032 8	62.6667
14	16.5079	4.6567	60.8333
15	20.5714	5.8030	74.0000
16	20.3810	5.7493	67.3333
17	19.8095	5.5881	67.5000
18	21.1429	5.9642	70.0000

On this basis, based on the visual design parameters of the multi-storey residential internal structure in **Table 1**, it is extracted and simulated, and a visual spatial distribution diagram of the high-rise building is obtained.

3.2. Analysis of experimental results

To verify the effectiveness of the proposed method, the experiment analyzes the extraction accuracy of the sample spatial layout image features by the proposed method, and the methods in literature [2] and literature [3]. The obtained results are shown in **Figure 4**.

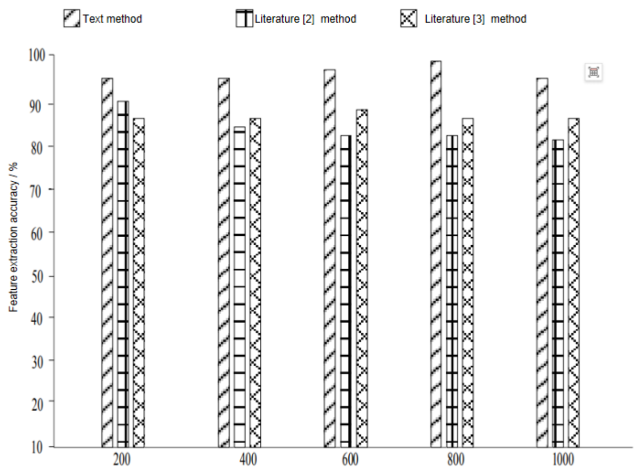

Figure 4. Analysis of sample space feature extraction accuracy by different methods.

As shown in **Figure 5**, as the extraction time continues to increase, there are certain differences in the extraction accuracy of sample space features by the three methods. Among them, the extraction accuracy of sample space features by the proposed method is up to about 98%; the extraction accuracy of sample space features by the method in literature [2] is up to about 91%; the extraction accuracy of sample space features by the method in literature [3] is about 89%. Compared with the other two algorithms, the algorithm proposed in this paper has higher accuracy, which proves that the algorithm proposed in this paper is effective.

Finally, this paper also compares the time spent by the two algorithms in extracting images, as shown in **Figure 5**.

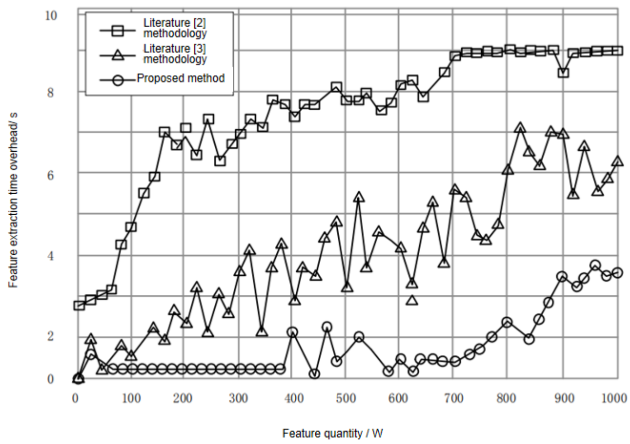

Figure 5. Time analysis of sample feature extraction by different methods.

As can be seen from **Figure 5**, the length of time for the three sampling characteristics is different. The extraction time of this method is 1.1 s, the extraction time of reference [2] is 7.8 s, and the extraction time of reference [3] is 3.2 s. The extraction time of this method is 3.8 s, 9 s in reference [2], and 6.1 s in reference [3]. The results show that this algorithm takes less than 4 s, while the other two algorithms take longer.

In order to integrate deep learning models into BIM software, we need to design a user-friendly interface. This interface should allow users to easily upload interior images and display processing results. At the same time, the interface should have the ability to exchange data with BIM software in order to combine the extracted features with other information from the building model. Once the model is trained and integrated into the BIM software, it can automatically extract spatial layout features from the uploaded indoor images. These characteristics can include room size, furniture layout, space utilization, etc. To facilitate user understanding, extracted features can be presented visually, such as heat maps, color coding, or interactive charts.

3.3. Cost-benefit analysis

(1) From the perspective of time cost, traditional manual evaluation methods rely on on-site investigation and manual measurement by professionals, which is not only time-consuming, but also inefficient. In the case of a typical 1000-square-meter high-rise interior space, manual evaluation can take days or even weeks to complete. The image processing method based on deep learning proposed in this paper, through automatic processing of image data, can complete the extraction of spatial layout features within a few hours, significantly shortening the evaluation cycle.

(2) From the perspective of manpower cost, the traditional manual evaluation

method requires a lot of manpower input, especially for large-scale construction projects, which may require the formation of a special evaluation team. This not only increases the operating cost of the enterprise, but also poses a challenge to the allocation of human resources. In contrast, the application of deep learning models greatly reduces the need for manpower, and only a small number of technicians are required to train and optimize the models to achieve efficient spatial layout feature extraction.

(3) In terms of implementation costs, although the initial development of deep learning models requires certain investment, including hardware equipment, software platforms and personnel training, these costs will gradually decrease with the maturity and popularity of the technology. Moreover, once the model is built and optimized, its operating costs are much lower than traditional manual evaluation methods.

4. Conclusion

Therefore, this paper uses deep learning technology to analyze the internal spatial layout of high-rise buildings, and analyzes it. On this basis, a method of extracting visual image points of interior spatial distribution of tall buildings based on boundary pixel feature reconstruction is proposed. On this basis, a visual model of interior space layout of high-rise buildings based on visual characteristics is proposed. This project takes high-rise buildings as the research object and the distribution of boundary parameters as the entry point to study the evolution law of degradation characteristics of the internal spatial layout of high-rise buildings and obtain its characteristic quantity. On this basis, the sparse feature decomposition principle of interior layout visualization images of high-rise buildings is established, and the sequence of boundary parameters is obtained by extracting feature-fuzzy state parameters. On this basis, a method based on deep neural network is proposed to control the convergence of model parameters and extract features.

This study also has limitations:

(1) Deep learning models typically require a lot of computational resources and time to train, which can be a limiting factor in practical applications. In addition, the complexity of the model and the adjustment of parameters may also lead to the instability and poor interpretability of the results.

(2) The indoor environment of high-rise buildings is complex and changeable, including different decoration styles, furniture layout and lighting conditions, which brings challenges to the training and recognition of models.

In the future, we need to study how to improve the interpretability of deep learning models and help users understand the decision-making process of models through visualization technology. At the same time, explore the application possibility of deep learning image processing technology in other fields, such as medical image analysis, industrial detection, etc.

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Conflict of interest: The author declares no conflict of interest.

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