A house detection algorithm based on neural network for aerial photography of unmanned aerial vehicle

Guilin Zhang[1,*], Minglei Wei[2], Jingde Wang[3], Yang Han[1], Yunmei Zheng[4]
1. State Grid Hebei Electric Power Co., Ltd. construction company, Shijiazhuang Hebei 050021, China
2. State Grid Hebei Electric Power Supply Co.,Ltd, Shijiazhuang Hebei 050021, China
3. Hebei Electric Power Engineering Supervision Co. LTD, Shijiazhuang Hebei 050021, China
4. Unisplendour Software Systems Co. LTD, Beijing 10084, China

CA Guilin Zhang email: 2015226080001@stu.scu.edu.cn
Minglei Wei email: weiminglei0885@163.com
Jingde Wang email: rqhdwjd@163.com
Yang Han email: saifeng321@foxmail.com
Yunmei Zheng email: ZhengYMei@126.com

Abstract: In view of the low accuracy and efficiency of manual detection for houses in remote areas, as well as the large security risks, this paper aims to conduct an in-depth study on the algorithm of UAV aerial image house detection based on neural network. Firstly, the UAV image house preprocessing method based on guided filtering is adopted. In view of the radiation distortion in the UAV aerial image house, the histogram matching method is adopted to reduce the impact of radiation distortion, so that the hue and brightness of the UAV aerial image house are consistent. The guided filtering method is used to solve the problem that the details of the house image are not obvious after the aerial image house is smoothed and denoised. Then, the house detection algorithm of UAV image based on depth neural network is used to detect the house image, and the time consumption of depth learning operation is analyzed. The house detection is carried out through depth separation convolution and calculation optimization, which is combined with YOLOv2 detection framework to improve the real-time property of house image detection while maintaining good performance of UAV aerial image house detection, Complete the research on house detection algorithm of UAV aerial image based on neural network. The experimental results show that the proposed method can effectively improve the efficiency and accuracy of house detection in aerial images, and has certain practical value.

Keywords: UAV aerial photography; House inspection; Guided filtering method; Depth neural network detection algorithm;

1. Introduction

In recent years, with the rapid development of the UAV industry, UAVs have been widely used in civil and military fields due to their small size, convenient use and strong viability. In the civil field, UAVs can play an important role in geological exploration, video monitoring and circuit inspection. In the military field, UAVs can carry out some difficult tasks such as route reconnaissance and intelligence collection in some dangerous and remote areas [1]. Target detection based on UAV aerial images is a hot topic in current research. Among them, houses are the main places for the daily life and production of the public. Relevant departments carry out urban planning according to the details of houses and buildings, and can effectively control illegal houses built privately. Therefore, it is of great significance to detect houses in aerial images.

In practical applications, when the UAV is taking aerial photos for detection, it cannot effectively ensure that the UAV is flying at the same altitude all the time, so there will be environmental factors and other interference, as well as light and climate will increase the uncertainty of detection. At the same time, the size of ground houses is also different, and it is difficult to detect houses with small areas. Therefore, how to detect houses in UAV aerial images and ensure the accuracy of detection is a problem that needs to be solved urgently in current UAV aerial image detection [2-3]. The effect of traditional UAV image house detection is poor, and it is also easy to be affected by external factors, so the real-time detection is poor. Therefore, based on neural network, this paper designs a UAV aerial image house detection algorithm based on neural network, and conducts in-depth research.

The innovations of this paper are as follows:(1) The pretreatment method of UAV image house based on guided filtering is adopted. In view of the radiation distortion in the UAV aerial image house, the histogram matching method is adopted to reduce the influence caused by radiation distortion, so that the hue and brightness of the UAV aerial image house are consistent. The guided filtering method is used to solve the problem that the details in the house image are not obvious after the house in aerial image is smoothed and de-noised. Then, the house detection algorithm of UAV image based on depth neural network is used to detect the house image, and the time consumption of depth learning operation is analyzed. The house detection is carried out through depth separation convolution and calculation optimization, which is combined with YOLOv2 detection framework to improve the real-time property of house image detection while maintaining good performance of UAV aerial image house detection. (2) Compared with other algorithms of house detection in UAV aerial images, the proposed method can effectively improve the accuracy and real-time of house detection in UAV aerial images.

2. Related work

Object detection technology is the basis of computer vision or a very important research direction. The combination of computer vision and UAV application is the key direction of this research. Zhu Xingkui et al. analyzed some problems such as dense targets, complex background and difficult target detection in the house in the UAV image, and proposed a house detection algorithm based on the combination of convolutional neural network and Transformer. The detection algorithm is based on YOLOv5 network and combined with Transformer structure to break the limitations of convolutional neural network and capture the global dependency with attention mechanism. Large scale house image feature map is used, and weighted bidirectional feature pyramid network is used to enhance house image feature propagation. The ability of the network to detect small house objects is improved. Data dimension reduction and sliding window are used to reduce network memory consumption and computation. The simulation experiment is conducted on the UAV dataset. The experimental results show that the proposed algorithm can effectively ensure the real-time property of house detection and show the detection performance of the model for UAV aerial images, but the overall detection accuracy of the algorithm is low [4].Chen Xu et al. proposed a house detection algorithm based on real-time UAV images by combining the characteristics of UAV aerial images such as complex background, high resolution and large difference in target scales. Analyze the impact of network width and depth on the house detection performance of UAV aerial images, use the convolution module to increase the receptive field to improve the utilization of spatial features, design and improve YOLOv5s of shallow network, and improve the house detection accuracy of UAV aerial images. The house feature fusion module SCAM is designed to improve the utilization rate of house image details by using local feature supervision, and improve the accuracy of house target classification by using multi-scale feature fusion. The house target position and classification decoupling detection structure are designed to improve the classification accuracy. The experimental results using UAV data sets show that the proposed detection model can effectively improve the detection accuracy of UAV image house detection, which exceeds the detection accuracy of traditional house detection methods. The migration experiment in remote sensing dataset proves that the improved model is effective. The proposed improved model has high target recognition rate, but the overall house detection efficiency is low [5].Lv Xiaojun, et al. and the current UAV aerial image target detection have some problems such as low detection accuracy and false detection. They propose a house detection method based on enhanced features for UAV aerial image. This method takes Faster R-CNN-ResNet-50-FPN as the basic model of detection. Then a new DetNet-59 aerial image house feature extraction network is proposed to enhance the features of flat FNN aerial image house feature fusion network. Soft NMS is introduced to solve the overlapping problem of housing targets. The proposed detection algorithm conducts simulation experiments on the dataset of VisDrone 2019. Under the condition of less time consumption, the accuracy of house detection is better than the commonly used house detection algorithm at the current stage. The experimental results show that although the algorithm can effectively improve the accuracy of house detection, it can not ensure the real-time detection [6].Zhao Kun et al. proposed a house target detection algorithm based on simple linear iterative clustering segmentation to solve some problems such as small targets and weak contrast in UAV aerial images. The contrast of the houses in the original aerial image is improved by preprocessing, the target area of the houses in the aerial image is segmented by Top hat fusion method, and the fine segmentation of the houses in the aerial image is completed by SLIC method, the results of SLIC segmentation are clustered by using the improved clustering method with noise, and the relevant features such as the target neighborhood entropy of the houses in the aerial image are extracted, The feature matching method is adopted to detect the house in aerial image, and the final UAV image house detection result is obtained. A strategy based on the combination of global detection and local detection is proposed to effectively improve the real-time property of house detection. Although this method can improve the performance of UAV image house detection, the detection accuracy is poor [7].

3. Preprocessing of uav aerial house image based on guided filtering

3.1 Geometric correction of house image

A mapping is constructed for the aerial image house before geometric correction and the aerial image house structure after geometric correction. Assume that it is a pixel in the aerial image house to be corrected, and the coordinates of the pixel point are deformed and expressed as:

$$\begin{aligned}\Delta x &= x\left(K_1 r^2 + K_2 r^4\right) + P_1\left(r^2 + 2x^2\right) + 2P_2 xy \\ \Delta y &= y\left(K_1 r^2 + K_2 r^4\right) + 2P_1 xy + P_2\left(r^2 + 2y^2\right)\end{aligned} \quad (1)$$

In formula (1), P_1 and P_2 represent coefficients of eccentric distortion, K_1 and K_2 represent coefficients of longitudinal distortion, (x_0, y_0) represents the coordinate of the main point O of the house image, and these related data can be obtained by UAV [8-9]. $x = x_i - x_0$, $y = y_i - y_0$ and $r^2 = x^2 + y^2$ at the same time.Assume that the point corresponding to point $P(x_i, y_i)$ after geometric correction of aerial image houses is $P(x_j, y_j)$, which means that the mapping relationship between aerial image houses before and after geometric correction is:

$$\begin{aligned}x_j &= x_i + \Delta x \\ y_j &= y_i + \Delta y\end{aligned} \quad (2)$$

But in Formula (2). The mapping relationship cannot ensure that the pixel points of the house image after correction are integer points, which is represented by formula (3):

$$P'(x_j, y_j) = \left(i + u, j + v\right) \quad (3)$$

In formula (3), i and j are integer parts of rows and columns of house image pixel points, and u and v represent decimal parts of house image pixel points. The house image pixel value of P' is expressed as:

$$\begin{aligned}& f(i+u, j+v) = \left(1-u\right)\left(1-v\right)f(i,j) + v(1-u)f(i,j+1) \\ & + u(1-v)f(i+1,j) + uvf(i+1,j+1)\end{aligned} \quad (4)$$

In formula (4), $f(i,j)$, $f(i+1,j)$, $f(i,j+1)$ and $f(i+1,j+1)$ correspond to the pixel values of 4 points P_1, P_2, P_3 and P_4 adjacent to P' on the house image before geometric correction.The pixel value of the P' point can be obtained by using the adjacent four pixel values, and the geometric correction of the distorted house image can be completed [10-11].

3.2 Optimization algorithm of steering filter

Spatial smoothing can also be called spatial smoothing. The main reason for using the guided filtering method is that this method can not only realize the bilateral filtering edge smoothing of the image, but also apply it to some scenes such as aerial image house enhancement and detection.

For some ordinary linear transform filters, the input aerial house image is I, the output aerial house image is S, the orientation function aerial house image is T, and the filtering result defined at the aerial house image pixel point j is expressed as:

$$S_j = \sum_i W_{ij}(T) I_j \quad (6)$$

In formula (6), i and j represent the subscripts of image pixels, the kernel function W_{ij} of the filter belongs to the weighting coefficient of the house image, and the kernel of the filter is expressed as:

$$w_{ij}^{bf}(I) = \frac{1}{K_i} \exp\left(-\frac{|x_i - x_j|^2}{\sigma_s^2}\right) \exp\left(-\frac{|I_i - I_j|^2}{\sigma_r^2}\right) \quad (7)$$

In Formula (7), x represents the coordinate of the house image, K_i represents the normalized parameter, and $\sum w_{ij}^{bf} = 1$, parameters σ_s and σ_r represent the similarity of the aerial house image space. Assume that the linear model of the pilot filter is expressed as:

$$S_i = a_k I_i + b_k, i \in W_k \quad (8)$$

In formula (8), the window function W_k represents the linear transformation of S centered on I at the house image pixel k, and the coefficients a_k and b_k need to meet the same linear coefficients [12-13]. In order to define the linear coefficient, the definition of output response q needs to meet the following requirements:

$$q_i = I_i - n_i \quad (9)$$

In Formula (9), n_i represents the noise in the aerial house image. The local linear model can effectively identify the image edges corresponding to the input and output, thus minimizing the difference between q and I, ensuring the transformation of the original linearity, and minimizing the window function W_k:

$$E(a_k,b_k)=\sum_{i\in wk}((a_kI_i+b_k-p_i)^2+\varphi a_k^2)\quad(10)$$

In Formula (10), φ represents the regularization parameter, and the coefficients a_k and b_k are obtained according to the linear transformation, expressed as:

$$a_k=\frac{\frac{1}{|w|}\sum_{i\in w_k}T_iI_i-\mu_kI_k}{\sigma_k^2+\varphi}\quad(11)$$
$$b_k=\bar{I}_k-a_k\mu_k$$

In Formula (11), μ_k represents the mean value of window w_k of guide image I, σ_k represents the variance of window w_k of guide image I, and $|w|$ represents the total number of image pixels, $\bar{I}_i=\left|\frac{1}{w}\right|\sum_{i\in w_k}I_i$.

Suppose that the image point is $I(x,y)$ after the house image is smoothed, and the user-defined matrix is F. After the convolution operation of $I(x,y)$ and F, a new expression of house image point $I'(x,y)$ is obtained, which is expressed by Formula (12) and Formula (13):

$$I'(x,y)=I(x,y)*F\quad(12)$$

$$F=\begin{pmatrix}0 & -0.8 & 0\\ -0.8 & 4 & -0.80\end{pmatrix}\quad(13)$$

In Formula (13), the user-defined matrix F is a differential operator, which can be used as a sharpening filter, and the aerial house image can be convolved to sharpen the filtering effect, effectively enhance the details in the aerial house image, and eliminate the fuzziness in the aerial house image [14-15].

4. House detection algorithm based on convolution neural network for uav aerial images

The computation of convolutional neural network is mainly composed of convolution computation, full connection layer computation and activation function computation. Because full connection layer computation takes a long time, in recent years, most deep neural network measurements are convolutional operations. Taking

Res-net18 as an example, when the input size is 224 * 224, the calculation amount composition of Res-net18 is shown in Table 1.

Table 1 Composition of Resnet18 Calculation Amount

Calculation category	Multiplication and addition times (M)	Proportion of calculation amount
convolution	1834.81	99.37%
Full connection	0.015	0.00075%
Activation function	11.37	0.63%
total	1846.20	100%

Combined with the above analysis, reducing the computation amount of convolutional neural network and the amount of data read and written in memory can reduce the time consumption of deep learning algorithm running on the CPU platform.

4.1 Optimization of depth separation convolution and computation

Suppose that the size of the convolution kernel of a certain convolution layer of the house image is $k \times k$, and the number of channels for input data is M. The feature layer size of house image output is $X \times Y \times N$. Among them, X represents the length of the image output layer, Y represents the width of the image output layer, and N represents the number of channels of the image output layer [16-17]. If the house image convolution layer is a common convolution layer, it is shown in Figure 1.

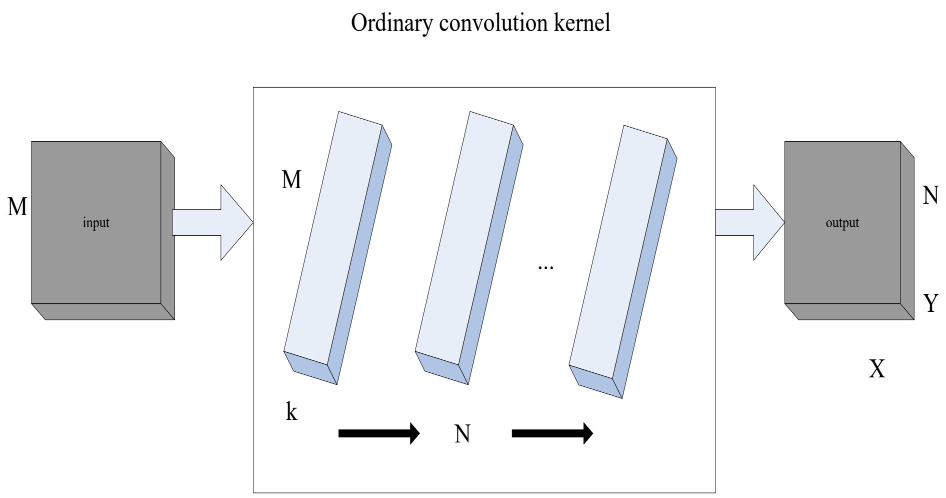

Figure 1 Ordinary convolution layer of house image

The parameter of ordinary convolution kernel is $k \times k \times M$. The ordinary convolution layer convolution core slides on the image input feature layer, and a data point on the output feature layer can be formed by any one sliding. The number of floating point numbers generated by the sliding of the convolution kernel is consistent with the number of parameters of the convolution kernel. Then the number of floating-point multiplication times of ordinary convolutional layer is expressed as:

$$cal = M \times X \times Y \times Y \times k \times k \quad (14)$$

Ordinary convolution can be represented by two special convolution layer combinations, which are called depth separation convolutions. It is shown by Figure 2.

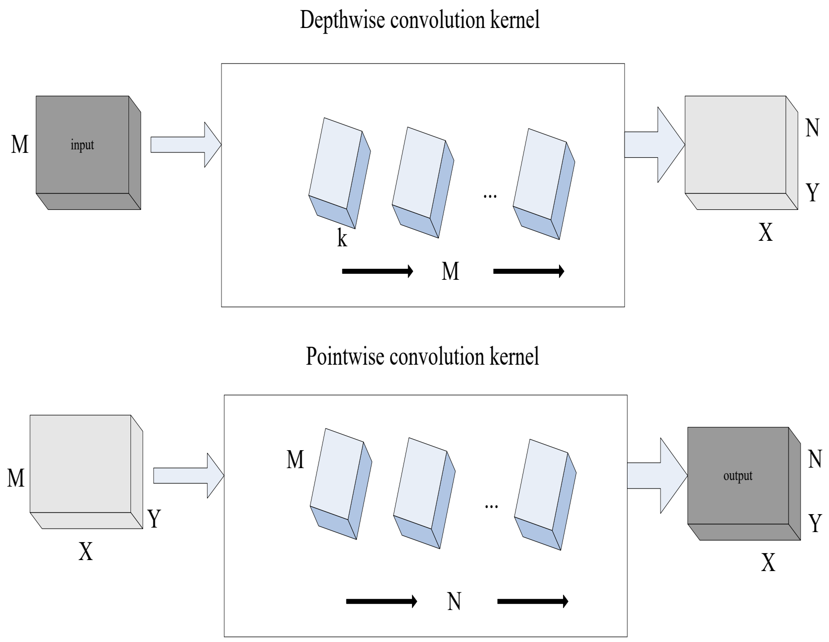

Figure 2 Convolution kernel of house image depth separation

For the input feature layer of aerial house image with M channels, M single channel convolution kernels with size of $k \times k$ are used to convolution on the input channel of aerial house image, and the feature layer of aerial house image output with size of $X \times Y \times M$ is obtained. The feature of each channel can be extracted, called $dephtwise$ convolution layer, and the calculation amount is:

$$cal_{depthwise} = k \times k \times X \times Y \times M \quad (15)$$

For the output features of the aerial house image of the previous M channels, the size of N channels is 1×1, and the convolution kernel of M channels is used to expand the convolution, thus obtaining the $X \times Y \times N$ output feature layer [18]. It can fuse the characteristics of each channel, which is called $po\mathrm{int}wise$ convolution layer. The calculation amount is:

$$Ratio = \frac{cal_{depthwise} + cal_{po\mathrm{int}wise}}{cal} = \frac{1}{k^2} + \frac{1}{N} \quad (16)$$

In Formula (16), N represents the number of channels of the output feature layer, and k represents the size of the convolution kernel. Take Res-net18 as an example. The value of N is between, and the value of k is 3. Therefore, the calculation amount can be reduced to 1/8 of the previous one by using the depth separation convolution.

4.2 YOLOv2 network optimization

Resnet is an image classification model. Compared with the straight cylinder structure of the neural network (shown in Figure 3), Resnet uses the residual structure (shown in Figure 4).

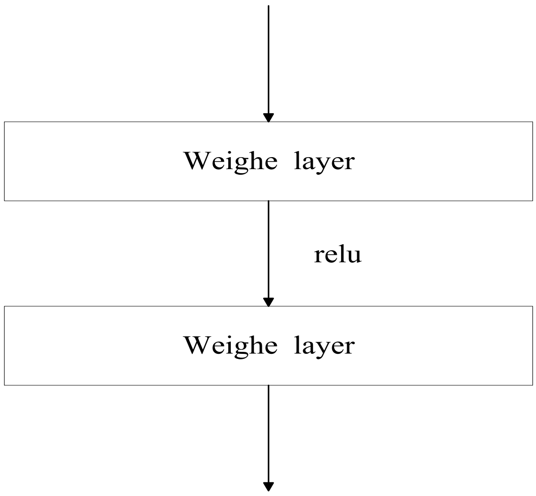

Figure 3 Structure of neural network straight cylinder

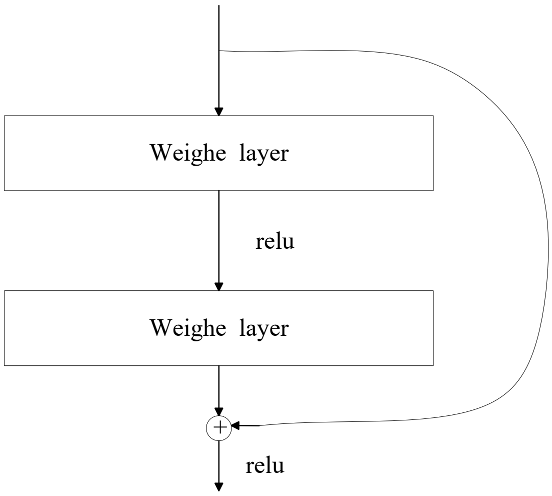

Figure 4 Structure of neural network residuals

The residual structure can effectively improve the ability of neural network expression, and prevent gradient loss in the network layer. Because Resnet shows excellent performance in computer vision tasks, Resnet18 is selected as the framework basic network of YOLOv2 to improve it.

According to the depth separation convolution and the calculation amount optimization calculation method, all convolution layers in Resnet18 are replaced by the depth separation convolution [19-20]. The improved neural network does not use convolution, but only contains two branches. After the improvement, only half of the channels in the structure of the neural network can be convolved, which can effectively reduce the amount of calculation, and also reduce the burden of reading the feature layer of aerial house images. Because the feature layer of the aerial house image can always be divided into left and right parts during the flow process, the data information between the left and right parts of the feature layer of the aerial house image does not flow, which will affect the expression effect of the house image. Therefore, the convolution layer in the Resnet18 network branch is transferred to the branch junction, and the convolution layer is used as the image data information fusion between channels. Therefore, the research of house detection algorithm for UAV aerial images based on neural network is completed.

5. Experimental result

In order to verify the effectiveness of the research on the house detection algorithm of UAV aerial images based on neural network proposed in this paper, simulation experiments are carried out. Table 2 shows the configuration of the experimental platform.

Table 2 Experimental Platform Configuration

Experimental configuration	data
To configure	Intel Core i5-2450M
operating system	Windows7
Memory	6GB
Simulation computing platform	Intel NUC

In this experiment, 50 UAV aerial house images are used for algorithm testing, and the results of 5 images are shown in Table 3.

Table 3 Comparison of house image feature points extracted by different methods

image	Preprocessing method of guided filtering	Literature [4] Method	Growth ratio
1	972	804	17%
2	1238	1001	19.0%
3	1315	1048	20.2%
4	1698	1368	19.4%
5	2203	1869	15.4

In this experiment, 50 UAV aerial house images are used for algorithm testing, and the results of 5 images are shown in Table 3. It can be seen from Table 3 that the number of feature points extracted from house images has increased by 15% - 20%. Based on the data statistics of all 50 house images, the number of feature points extracted by the method proposed in this paper can increase by about 16% on average compared with the method proposed in literature [4]. This shows that the house image pre-processing method proposed in this paper can effectively reduce the house image correction distortion and enhance the house image details, laying a good foundation for subsequent house image detection. Figure 5 shows the comparison of the detection efficiency of the house image detection using the method proposed in this paper with that in [4] and [5].

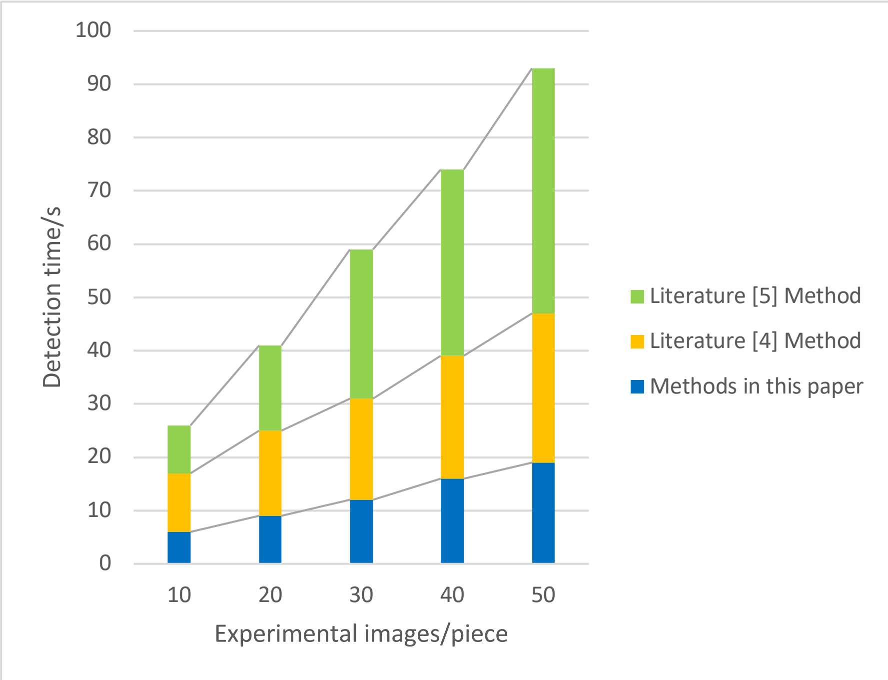

Figure 5 Comparison of house detection efficiency of UAV aerial images with different methods

It can be seen from the analysis of Figure 5 that although the detection time of UAV aerial image houses using the method proposed in this paper has slightly increased, the overall increase is small, and the detection time increases by 13s. However, the detection time of UAV aerial image houses using the method proposed in literature [4] increases with the increase of experimental images, and the detection time increases by 17s, The detection time of UAV aerial image house using the method proposed in document [5] increases by 37s from the beginning of the experiment to the end of the experiment, which shows that the UAV aerial image house detection algorithm proposed in this paper has a faster detection efficiency in the same experimental image detection. Figure 6 shows the comparison of the undetected rate of the house image detection using the method proposed in this paper with that in literature [6] and literature [7].

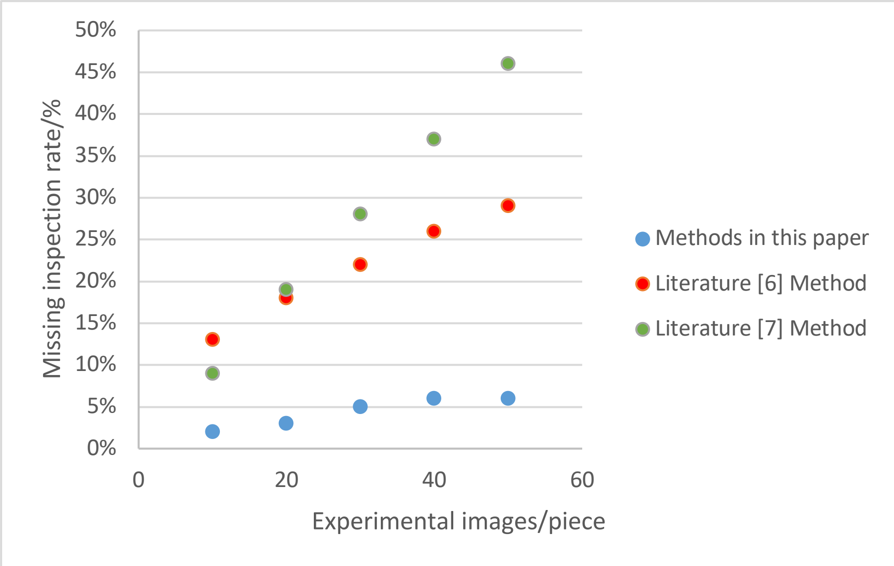

Figure 6 Comparison of undetected rate of house detection in UAV aerial images by different methods

It can be seen from Figure 6 that with the increase of experimental images, the undetected rate of the image house detection using the method proposed in this paper has slightly increased, but the overall increase is small, which has been kept below 6%. However, with the increase of experimental images, the undetected rate of house detection in UAV aerial images using the methods proposed in literature [6] and literature [7] gradually increases. Among them, the undetected rate of house detection in UAV aerial images using the methods proposed in literature [7] is as high as 46%, indicating that the methods proposed in literature [7] are not applicable to house detection in UAV aerial images, The method proposed in this paper can effectively reduce the missing rate of house detection in UAV aerial images, thus improving the precision of house image detection. Figure 7 shows the comparison of the accuracy rate of house image detection between the method proposed in this paper and that in literature [4] and literature [6].

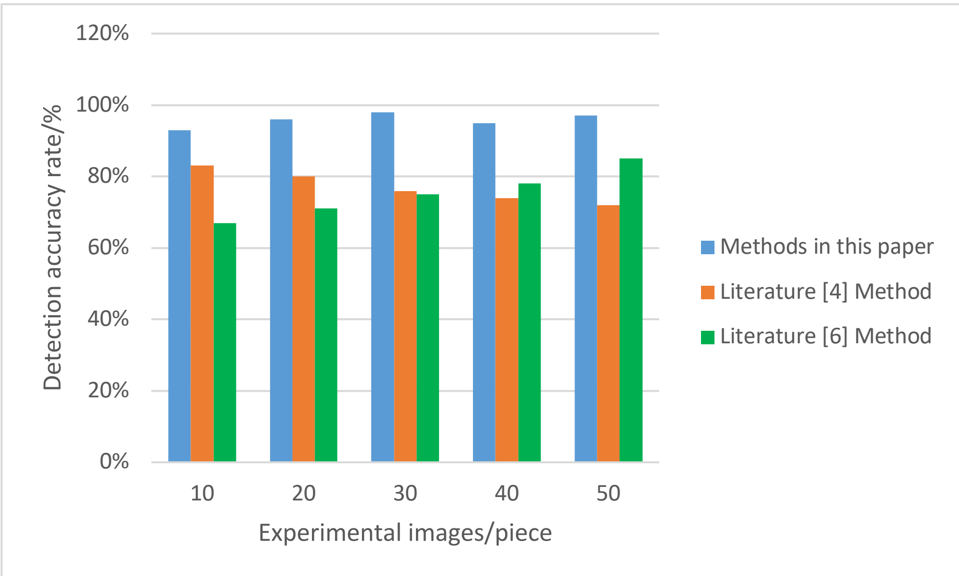

Figure 7 Comparison of accuracy rate of house detection in UAV aerial images with different methods

It can be seen from Figure 7 that the method proposed in this paper has always been highly accurate in detecting houses in UAV aerial images, and can effectively detect all details of houses in aerial images. Although the method proposed in literature [4] has a high detection accuracy at the beginning of the experiment, the detection accuracy gradually decreases with the continuous increase of images, indicating that the stability of this method is poor, The accuracy rate of house detection in UAV aerial images using the method proposed in literature [6] shows a gradual upward trend, but the increase is small, and it does not reach 90% until the end of the experiment. This shows that the method proposed in this paper can ensure the accuracy of house detection for UAV aerial images, thus reducing the workload of subsequent image processing.

6.Conclusions

With the gradual development and maturity of UAV aerial photography technology, the house detection of UAV aerial images has important research value. In this paper, firstly, the image preprocessing method based on guided filtering is used to preprocess the UAV aerial image house, and then the UAV aerial image house detection algorithm based on depth neural network is used. The detection network designed for the house in the UAV aerial photography data can effectively improve the accuracy of house image detection. The use of depth neural network can effectively improve the efficiency of house image detection. However, this paper does not adopt different strategies to deal with different perspectives, and we hope to conduct detailed research and improvement in the follow-up work.

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