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Research on Image Denoising Algorithm in UAV Line Inspection System Based on Matrix Recovery

Li Cong [1], Hongfeng Li [2], Hua Wang [3], Jia Li [1], Peng Jin [2], Chao Zhang [3]

[1]Information and Communication Company, State Grid Jilin Electric Power Co., Ltd., Changchun 130021, China

[2]State Grid Jilin Electric Power Co., Ltd., Changchun 130021, China

[3]JiLin Province Siji Technology Co., Ltd, China

Abstract

With the continuous development of the power grid, the power communication network plays an important support and guarantee role in the entire power system. In 2021, the communication lines in Jilin Province reached 111.2028 million kilometers, and they were exposed to the natural environment for a long time. Regular inspections were required to detect faults as soon as possible and make corresponding treatments. In recent years, unmanned aerial vehicles have been used in the inspection work of the communication lines of the State Grid Jilin Electric Power Co., Ltd. However, due to the influence of light intensity and atmospheric turbulence, the quality of the collected images cannot meet the actual work requirements. This article mainly uses matrix recovery The (Matrix Recovery) image denoising method removes the noise in the image collected by the drone, improves the detection accuracy, efficiency and reliability of the communication line, and improves the efficiency and level of line inspection.

Keywords

UAV, communication line inspection, image denoising, matrix restoration.

1. Introduction

Communication line inspections play an important role in maintaining the safety, stability and efficient operation of the power grid. Communication lines are generally distributed across regions and exposed to the outdoors for a long time. Due to continuous mechanical tension, lightning strikes and material aging, they are affected. Need to do regular inspection and maintenance. The traditional manual patrol method, as shown in Figure 1, has the disadvantages of large workload and difficult working environment. The labor cost is relatively high. For areas with harsh natural environment, the completion rate of manual patrol is low. At present, UAVs are widely used in communication line inspection, as shown in Figure 2 [1]. UAVs use full-spectrum cameras and sensors to patrol the communication lines, increase the speed and efficiency of the line patrol, and expand the line pat The main direction is to open a new era of line inspection [2].

Compared with traditional manual patrol methods, UAV patrols have unique advantages; 1) UAV patrols have low requirements for the flight environment. In remote areas with complex geographic environments, UAVs can determine faster Fault points, real-time transmission of the situation on the spot, reducing the time for inspection personnel on foot; 2) UAVs can complete line patrol tasks with power on, and take close shots of the working conditions of communication lines and related equipment; 3) UAV patrols Line work guarantees the safety of line inspectors to a certain extent and reduces line inspection costs [3].

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Figure 1 Manual tour view

Figure 2 UAV tour view

At present, compressed sensing based on data mining has made important progress in theory, and these advances have made sparse representation a more effective way of data representation. Matrix restoration is to extend the sparse representation of vector samples to the case of matrix low-rank. It is another important data acquisition and representation method after compressed sensing. Matrix recovery is to express the data matrix as the sum of low-rank matrix and sparse noise matrix, and then recover the low-rank matrix by solving the kernel norm optimization problem. Under reasonable assumptions, the convex relaxation function of the objective function can be optimized, and the optimal solution of the original problem can be accurately given, so as to obtain a clear low-rank image.

State Grid Jilin Province Electric Power Co., Ltd. uses drones to take pictures of communication cables and towers, and transmits the taken images to the ground monitoring station for storage in real time, so as to determine the fault point as soon as possible and grasp the operation of the entire line for follow-up Prepare for state analysis of communication lines. However, due to problems such as mechanical shock and lens swing in the process of UAV line inspection, the collected images are blurred. This paper proposes a matrix recovery-based UAV image denoising algorithm and performs Simulation verification, experimental results show that the image denoising algorithm proposed in this paper can effectively remove Gaussian noise, and greatly improve the efficiency and level of UAV line tracking.

2. UAV line patrol system composition

The UAV patrol system consists of three parts: UAV flight control system, UAV positioning information system and data processing system. The system composition is shown in Figure 3.

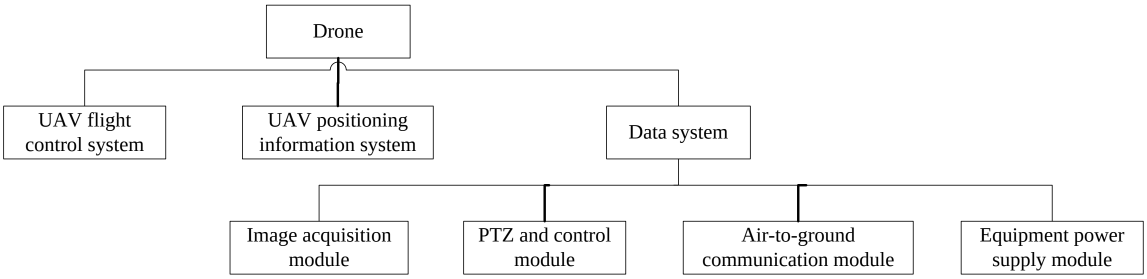

Figure 3 Composition of UAV line patrol system

The data processing system includes image acquisition module, air-ground communication module, equipment power supply module, pan-tilt and control module. The image acquisition module performs a series of image processing such as filtering, denoising and edge extraction on the images collected by aerial photography; the air-ground communication module mainly transmits the collected data to the monitoring room for further analysis and diagnosis; the equipment power supply module is the built image The acquisition module and communication equipment supply power; the pan-tilt and control module control the shooting angle of the camera and various equipment [4]. In the power communication system, the EWG-II model UAV is used, and its main technical parameters are shown in the following table:

Table 1 Technical parameters of UAV

Technical parameter	EWG-II
Takeoff weight	16kg
Maximum flight speed	110km/h
Cruising speed	40km-110km/h
Flying height	100-5000m
Sailing distance	20km
Flight time	>2h
Span	2.2m
Captain	1.55m
Control radius	2km
Task load capacity	3kg

3. Research on Image Denoising Algorithm

In the image acquisition module of the UAV line patrol system, due to various degrees of influences such as optical system distortion, relative motion, atmospheric turbulence, etc., the image is blurred and distorted and the quality is reduced, which affects the display of the line patrol effect and reduces the line patrol efficiency. Therefore, this summary introduces the existing image denoising methods to suppress noise and extract useful signals to meet the requirements of image processing.

3.1. Mean filter

Mean filtering is also called linear filtering. The main method is to construct a pixel template. The selection of the template is based on the current pixel (x, y) and several surrounding pixels, and the average value of all pixels in the template is used to replace the current pixel value. Mean filtering can be understood as the geometric neighborhood averaging method. After the same processing is performed on each pixel in the image, the mean filtering process of the entire image is completed to form a processed image.

Assuming that the original image is $f(x, y)$, the template size is 5*5 (its size and shape depend on the actual situation), the processed image $f(x, y)$ can be expressed as:

$$f'(x, y) = \frac{1}{5*5}\sum_{i=1}^{5}\sum_{j=1}^{5} f(x+i, y+j)$$

The mean filter using the geometric neighborhood averaging method is suitable for particle noise, but in the process of linear filtering, blur will also occur, and the degree of blur is proportional to the number of surrounding pixels.

3.2. Median filter

Median filtering can be understood as a non-linear smoothing filter. The main principle is that the pixel value of the current pixel (x, y) can be replaced by the median value of several surrounding pixels.

Assuming that the original image is $f(x, y)$, the two-dimensional median filter with the filter window of S can be expressed as:

$$f^*(x, y) = \mathrm{Med}\left\{ f(x+s, y+t), (s, t) \in S(x, y) \right\}$$

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The use of a nonlinear smoothing filter is suitable for isolated noise points. For pixel values with larger gray values of pixels, the median value of surrounding pixel values can be used instead, which can effectively eliminate isolated noise.

3.3. Adaptive Wiener Filter

Adaptive Wiener filtering can be understood as minimizing the mean square error of the filter output. The larger the local variance, the stronger the smoothing effect.

Suppose the original image is $f(\mathrm{x},\mathrm{y})$, the image after adaptive Wiener filtering is $f'(\mathrm{x},\mathrm{y})$, and the target is the minimum mean square error $e^2 = E(f(\mathrm{x},\mathrm{y}) - f'(\mathrm{x},\mathrm{y}))^2$.

The adaptive Wiener filtering method is suitable for white noise and can retain the edges and high frequency parts of the image, but it has the disadvantage of a large amount of calculation. The experimental results show that the effect of this method is better than that of the mean filter.

4. Research on Denoising Algorithm of Matrix Restoration Image

In recent years, with the in-depth research and application of Compressed Sensing theory and Sparse Representation algorithm, matrix restoration has become a research hotspot in the fields of machine learning, pattern recognition and computer vision. However, compressed sensing and matrix restoration have their own emphasis on the processing objects. Compressed sensing theory focuses on the sparsity of the signal, and matrix restoration refers to the sparsity of the matrix, that is, the low rank of the matrix [5].

When a matrix is low-rank or sparse, and there are only some elements, the matrix recovery algorithm recovers the complete matrix through some linear (non-linear) operation [6]. In this paper, the image denoising method of matrix restoration is used to denoise the image collected by the UAV's line patrol, which can remove Gaussian noise, impact noise and fringe noise at the same time.

Assume that the observation image matrix $\mathbf{D} \in R^{m \times n}$ is generated by a low-rank matrix with damaged elements $\mathbf{A} \in R^{m \times n}$. Noise can be expressed as an error matrix $\mathbf{E} \in R^{m \times n}$, namely $\mathbf{D} = \mathbf{A} + \mathbf{E}$. Because part of the data $\mathbf{D}$ affected by noise, $\mathbf{E}$ is a sparse matrix [7], and the simple representation of matrix recovery is as follows:

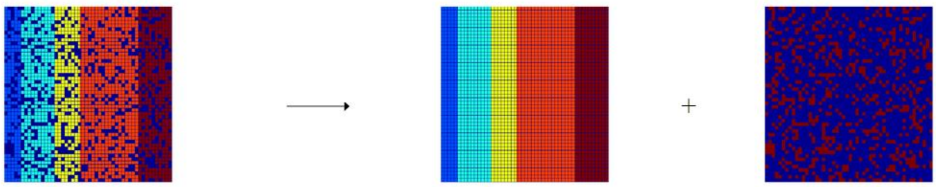

Figure 4 Simple representation of matrix recovery image

The ideal (no noise) robust principal component analysis RPCA can be expressed as:

$$\mathbf{D} = \mathbf{A} + \mathbf{E} \tag{1}$$

Among them, $\mathbf{A}$, $\mathbf{E}$ is unknown, but $\mathbf{A}$ is low-rank and $\mathbf{E}$ is sparse, so that the matrix $\mathbf{A}$ can be restored by the optimization problem, and the following optimization model can be constructed to express this problem:

$$\begin{aligned} &\min_{\mathbf{A},\mathbf{E}} \ rank(\mathbf{A}) + \gamma \|\mathbf{E}\|_0 \\ &s.t. \ \ \mathbf{A} + \mathbf{E} = \mathbf{D} \end{aligned} \tag{2}$$

The objective function is the rank of matrix A and the zero norm of matrix E, that is, the number of non-zero elements of E, which λ represents the weight of noise. However, the above optimization model is an NP-Hard problem and there is no effective algorithm. If you can find a suitable λ, you can accurately restore $(\mathbf{A}_0,\mathbf{E}_0)$. Since the kernel norm of the matrix is the convex hull of the matrix rank, it is expressed as: $\|\mathbf{A}\|_* = \sum_i \sigma_i(\mathbf{A})$, 1 norm is used instead of 0 norm, and the formula (2) can be relaxed, resulting in the following Convex optimization problem:

$$\begin{aligned} &\min_{\mathbf{A},\mathbf{E}} \ \|\mathbf{A}\|_* + \lambda\|\mathbf{E}\|_1 \\ &s.t. \quad \mathbf{A}+\mathbf{E}=\mathbf{D} \end{aligned} \tag{3}$$

By solving the convex optimization problem represented by (3) above, low-rank matrices and sparse matrices can be obtained, and low-rank matrices are matrices without noise interference.

5. Simulation and implementation

At present, the UAV patrol system has been applied in the power communication patrol of Jilin Province. However, due to the influence of factors such as outdoor environment changes, atmospheric turbulence and camera jitter, obstacles and other objective conditions will also affect the UAV collection. The image produces a certain amount of interference, which will directly affect the quality of communication line patrol. In the UAV communication line patrol system, the accuracy of image collection is a crucial step to improve the efficiency and level of line patrol.

Aiming at the characteristics of Gaussian noise in the images taken by the UAV line inspection, this paper uses Matlab2014 simulation software to process the image obtained by the UAV line inspection system image acquisition module. The image shown in Figure 5 (a) is ideal in this case, there is no noise on the line-following image, the gray level L=256, and the image size $m\times n = 512\times 328$. Figure 5 (b) shows an image with a Gaussian noise density of 40%.

Figure 5 (a) Image without noise

Figure 5 (b) Noisy image

Since the image matrix shown in Figure 3(b) has noise interference, the convex optimization recovery model shown in the above formula (3) is established. In order to solve the above convex optimization model, the augmented Lagrangian function is constructed as shown in formula (4), which λ is the noise weighting coefficient, and the value is $1/\sqrt{\max(\mathrm{m},\mathrm{n})}$, m and n are the dimensions of the noise image matrix.

$$L(\mathbf{A},\mathbf{D},\mathbf{E},\mathbf{Y},\mu) = \|\mathbf{A}\|_* + \lambda\|\mathrm{E}\|_F^2 + \langle \mathbf{Y}, \mathbf{D}-\mathbf{A}-\mathbf{E}\rangle + \frac{\mu}{2}\|\mathbf{D}-\mathbf{A}-\mathbf{E}\|_F^2 \tag{4}$$

For the augmented Lagrangian function constructed in (4), first set $\mathbf{Y}=0,\mathbf{E}=0$ and $\mu_0=0$, and set the iteration stop condition at the same time. In each iteration, first perform singular value decomposition on $\mathbf{D}-\mathbf{E}_k+\mu_k^{-1}\mathbf{Y}_k$, as shown in formula (5):

$$(\mathbf{U},\mathbf{S},\mathbf{V}) = \mathrm{svd}(\mathbf{D}\text{-}\mathbf{E}_k+\mu_k^{-1}\mathbf{Y}_k) \tag{5}$$

Use the matrix $\mathbf{U}, \mathbf{S}, \mathbf{V}$ obtained in the singular value decomposition to reconstruct the matrix $\mathbf{A}_{k+1}$, as shown in formula (6); reuse $\mathbf{A}_{k+1}$ and $\mathbf{Y}_k$ matrix construction $\mathbf{E}_{k+1}$, as shown in formula (7); finally reuse $\mathbf{A}_{k+1}$, $\mathbf{Y}_k$ and $\mathbf{E}_{k+1}$ update $\mathbf{Y}_{k+1}$, as shown in formula (8), The iteration is terminated until the iteration stop condition is met, that is $\mathbf{A}_{k+1}$, an image without noise interference.

$$\mathbf{A}_{k+1} = \mathbf{U}\mathbf{S}_{\mu_k^{-1}}[\mathbf{S}]\mathbf{V}^T \tag{6}$$

$$\mathbf{E}_{k+1} = \frac{\mu}{\mu + 2r}(\mathbf{D} - \mathbf{A}_{k+1} - \mathbf{E}_{k+1}) \tag{7}$$

$$\mathbf{Y}_{k+1} = \mathbf{Y}_k + \mu_k(\mathbf{D} - \mathbf{A}_{k+1} - \mathbf{E}_{k+1}) \tag{8}$$

According to the above derivation steps, the noise-containing image shown in Figure 3 (b) is denoised, and a noise-free interference image is obtained as shown in Figure 6.

Figure 6 Denoising image

We use the mean square error $ErrC$ as the denoising effect evaluation standard, and the mean square error is expressed as:

$$ErrC = \frac{\|\mathbf{M} - \mathbf{A}\|_F}{m \times n}$$

Among them, $\mathbf{M}$ represents the original image, $\mathbf{A}$ represents the image denoised by the matrix restoration algorithm, m and n is the dimension of the image. It is stipulated here that the smaller the root mean square error, the better the denoising effect.

In this simulation experiment, the mean square error is 0.03. From the experimental results, it can be seen that the image denoising algorithm based on matrix restoration can denoise the noisy images obtained by the UAV line patrol image acquisition system well, improve the image quality, and realize the detailed understanding of the line fault A more precise goal opens a new era of communication circuit inspection.

6. Conclusion

With the development of the power system, the stability of the power communication network plays an important role in the reliable operation of the power system, and the communication line inspection has become a must-check item in the spring and autumn inspection. Due to the time-consuming and labor-intensive manual patrol and the existence of great safety risks, State Grid Jilin Electric Power Co., Ltd. is gradually forming a communication line patrol mode that "unmanned aerial vehicle patrol is dominant and traditional patrol is complementary". Aiming at the problem of unclear and fuzzy captured images caused by other factors such as the illumination of the UAV acquisition system, this paper uses matrix recovery algorithm to remove the noise in the acquired image, save the details of the image, improve the image quality,

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and improve the efficiency and reliability of the line inspection , becoming the main development direction of future power communication system line inspection.

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