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Challenges and Prospects of Power Transmission Line Intelligent Monitoring Technology

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Abstract: The power transmission line often operates under the harsh environment, for example it works under very cold or high temperature, high wind speed, high rain, high snow weather; and the natural accident could make it work unnormal. And then the city or factory should loss electric power. So, it is important to ensure the power transmission line work normal under lots of uncertain statuses, the intelligent on-line monitoring technology or system is necessary. This paper mainly reviews three kinds of researches in this fields, the first is the video or infra surveillance in the transmission line monitoring; the Second the UAV and line inspection robots using in transmission line monitoring; the third the weather and the natural accident modeling in the transmission line monitoring. In the end, the prospects and challenges of power transmission line monitoring is presented.

Keywords: Power transmission Line, UAV, video or infra surveillance, the weather and the natural accident modeling.

Introduction

The power transmission line is foundational facility of station grid. There are lots of personal knowledge and researches in this fields, and it can be divided into four categories.

The first is about video and infra surveillance, include the digital image processing and recognition method. For example, the method of color space variable[1], 3D reconstruction of icing transmission lines [2], fractal algorithms of faults identification [3].

The second is UAV and line inspection robots using in the transmission line detection and diagnosis. For example, the tower and line tracking [4], broken strand detection and diagnosis [5], and so on.

The third is modeling forest fire and other phenomenon even to combine with the numerical weather prediction. For example, the evaluation on flashover risk of the air gap between line and tower [6], dynamic ice process [7], and so on.

The fourth is line measurement technology, faults diagnosis and location method, for example, the current status and development trend of AC transmission line [8].

The manuscript reviews and analyzes these technologies. It is very useful in developing the monitoring system of power transmission line, for example, the Ultra High Voltage DC transmitting line and AC transmitting line are widely used in state grids, and there is necessary to review the online monitoring technology.

The paper is arranged as follow: in Section II, the video and infra surveillance technology are presented; in Section III, the UAV and line inspection robots technology are discussed; in Section IV, the harsh weather and accident model are reviewed; in Section V, the line parameter measurement, the faults diagnosis and location technology are described, in the end, the prospects and challenges of power transmitting line monitoring system are given in the conclusions.

The Video and Infra Surveillance Technology

There are some applications in these fields. In paper [9][10] , the corona discharge in high voltage electrical equipment is inspected by the UV imaging technology, the insulation defects in these images are processing, analyzing.

In the paper [11], the accurate infrared temperature of electric power equipment is test, standardization. And then the atlases Database is established and applicated.

The paper [12] gives an example of the Khingan area in eastern Inner Mongolia, the temperature of this area always declines to −40˚C, especially in winter, and it is likely to cause transmission line to freeze and results in tripping accidents.

To simplify the main problems in video and infra surveillance technology, here gives some solution examples of icing detection.

At present, there are three main methods for monitoring ice thickness of transmission lines and insulators: The first: Monitoring ice thickness of transmission lines based on mechanical model, measuring tension and inclination angle by installing sensors on conductors or insulators; The second: Using capacitance/digital ice thickness sensor to detect the ice thickness of transmission line. The third: Video image monitoring method can measure the ice thickness by extracting boundary contours. In the third method, the boundary contours of insulators before and after icing should be extracted by the edge detection algorithm, and then the icing thickness was calculated [13][14][15]. The identification algorithms and processing of insulator icing are: firstly, the insulator is located and detected in the transmission line image. Then the image is preprocessed, segmented and edge extracted in this area; in the end, the boundary contour of the insulator is proposed, and the pixel area of the area before and after icing is compared, and whether there is icing or not is icing is preliminary judgement [16][17][18].

Template Matching Principle

$$s(r, c) = s\{t(u, v), f(r + u, c + v); (u, v) \in T\} \tag{1}$$

The simplest similarity measure is to calculate the sum of squares of all the differences between the template and the image [19][20][21] .

$$s_s(r, c) = \frac{1}{n}\Sigma_{(u, v) \in T} (t(u, v) - f(r + u, c + v))^2 \tag{2}$$

Insulator Image Region Segmentation

The image segmentation is to divide the image into several separate and qualitative regions according to certain rules. The maximum interspecific variance method is a simple, adaptive and widely used method for threshold selection [21]. f (m, n) is the gray value of M * N image at (m, n) points, and the gray level is K. The range of F (m, n) is [0, K - 1]. If P (i) is the frequency of gray value I in the image, then there is (3).

$$p(i) = \frac{1}{M \times N}\Sigma_{f(m, n) = i} 1 \tag{3}$$

When the selected threshold value is gray value t, the object and background are segmented by comparing the size of F (m, n) and threshold. The proportion of object and background in the image is respectively (4) and (5):

$$\omega_0(t) = \Sigma_{0 \le i \le t} p(i) \tag{4}$$

$$\omega_1(t) = \Sigma_{i > t} p(i) \tag{5}$$

The average is (6) and (7).

$$u_0(t) = \Sigma_{0 \le i \le t} \frac{i*p(i)}{\omega_0(t)} \quad (6)$$

$$u_1(t) = \Sigma_{i > t} \frac{i*p(i)}{\omega_1(t)} \quad (7)$$

Total mean of objective and background is (8).

$$u = \omega_0(t)\, u_0(t) + u_1(t)\, \omega_1(t) \quad (8)$$

Then the variance between classes is (9).

$$E = \omega_0(t)(u_0(t) - u)^2 + (u_1(t) - u)^2\, \omega_1(t) \quad (9)$$

Sub Boundary Extraction

The essence of edge detection is to use some algorithm to extract the boundary between the object and the background in the image. The change of image gray level can be reflected by the gradient of image gray level distribution. Therefore, the edge detection operator can be obtained by local image differentiation technology. The main edge detection operators are Robert, Sobel and Canny.

Canny edge detection operator uses the first-order directional derivative of two-dimensional Gaussian function (equation 10) in any direction as a noise filter, and filters the image by convolution with F (x, y). Then, the filtered image is searched for the local maximum of the image gradient to determine the edge of the image [22] [23].

$$G(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(\frac{-(x^2 + y^2)}{\sigma^2}\right) \quad (10)$$

Color Space Variable and Transmission Line Image Processing

Transmission line image processing includes image graying, denoising, contrast enhancement, feature extraction and feature matching.

In the process of transmission line image taking, the background of transmission line image is different due to different factors such as illumination intensity, environment and weather conditions. Common background types are: dark background, normal background, bright background, sky with blue background, sky with orange-red background, snow with white background and mountain with dark green background [21][24].

Because of environmental factors, the details of the captured image are not obvious, which brings great interference to image feature extraction. The purpose of image preprocessing is to eliminate these effects as much as possible. Some import image processing technologies are:

1) Gauss filtering is a kind of linear filtering. Its basic principle is to use a template to traverse the pixels one by one. Each pixel in the range of the template corresponds to a certain weighted value. The weighted average gray value of the pixels included in the template is used to replace the gray value of the central pixel of the template. Its mathematical expression is (11):

$$z(k, l) = \sum[a_{ij} \times y(i, j)]/n \quad (11)$$

S represent the size of the template; y (i, j) represent the gray value of each pixel i n the template; Z (k, l) represent the gray value of the central pixel of the module; n is the number of pixels included in the template; ij a represents the weighted value at (i, j) coordinate points [24].

2) Hough line transformation is a classical algorithm for line detection. The basic principle is to transform points in image coordinates into lines or curves in another coordinate system by coordinate transformation. Because points in the same line are represented as intersections of multiple lines or curves in another coordinate system, the number of intersections can be determined [25].

3) Morphological operations Corrosion and expansion are the most basic morphological operations. Corrosion is used to eliminate noise points smaller than structural elements, while expansion is used to fill holes in the target. Open and closed operations can be defined by basic corrosion and expansion operations. Open operation is a process of corrosion and expansion, which can eliminate the fine noise on the image and smooth the boundary of the object; Closed operation is a process of expansion and corrosion, which can fill the small holes in the object and smooth the boundary of the object [26].

Infrared Imaging System for Transmission Line

With the improvement of frame frequency and resolution of thermal imaging equipment, the reliability and accuracy of infrared thermal imaging technology have been greatly improved, and the application field has been further extended. Because the processing technology of image sequence has a great impact on the effect of thermal wave detection, the main processing methods of active infrared thermal image sequence are non-linear [27].

Hidden corrosion detection of aircraft structures, such as sex regression, linear interpolation and pulse phase method, has also begun to applied into thermal wave imaging technology. For in image matrix processing, the size of the covariance matrix is the number of rows and the number of rows in the image, so, some decrease dimension methods are used [28].

PCA

PCA is a method of analyzing data in statistics. Its purpose is to project data from the original high-dimensional space to a low-dimensional vector space through a special vector matrix. The main information of the data is saved after dimensionality reduction, so that the data can be easily processed. Expressed in the form of vectors [29]:

$$F = [F_1, F_2, \ldots, F_n] \tag{12}$$

The larger the eigenvalue corresponding to the orthogonal basis of thermal wave image sequence, the greater its contribution to reconstruction, so the eigenvectors with small eigenvalues can be ignored. Thus, the first D principal component can be used to reconstruct the model.

$$\hat{F} = \sum_{i=1}^{d} u_i^T Fu_i \tag{13}$$

Triangle Orientation Discrimination Threshold Measure Method

Triangle Orientation Discrimination Threshold, abbreviated as TOD method. This method uses equilateral triangles of different sizes and contrast as test splines. Through infrared imaging system, the observer judges the orientation of triangles several times, and obtains the relationship curve between threshold contrast and triangle size corresponding to 75% correct judgment probability. This curve is similar to MRTD curve, which synthetically characterizes the inherent performance of the infrared imaging system [30].

The UAV and Line Inspection Robots Using in the Transmission Line

Now, various sensors installed on poles, towers and power equipment are used to monitor the operation of power grid instead of manual inspection. However, due to the harsh natural environment at wiring sites, extreme changes in temperature, animal manure, electromagnetic interference and power supply problems of monitoring system itself, it is difficult for the system to operate effectively and maintain. As a result, 70% of the current sensitive monitoring system of transmission lines is stopped.

At present, the main maintain of transmission lines in domestic power grid are still manual patrol. To improve the effective, power units have successively adopted advanced technologies such as manned helicopters, robots and unmanned aerial vehicles to inspect high-voltage transmission lines[31]. Unmanned aerial vehicle (UAV) has attracted wide attention in this field due to its advantages of compact, convenient, easy to operate, low cost, fast operation and strong adaptability.

Tower and Traverse Tracking Algorithm

In this system, there are three coordinate system: Geodetic coordinate system, spherical center rectangular coordinate system and station center horizontal rectangular coordinate system.

The Figure.1 shows the Flow chart of tower tracking algorithm for power transmission line inspection based on UAV [4].

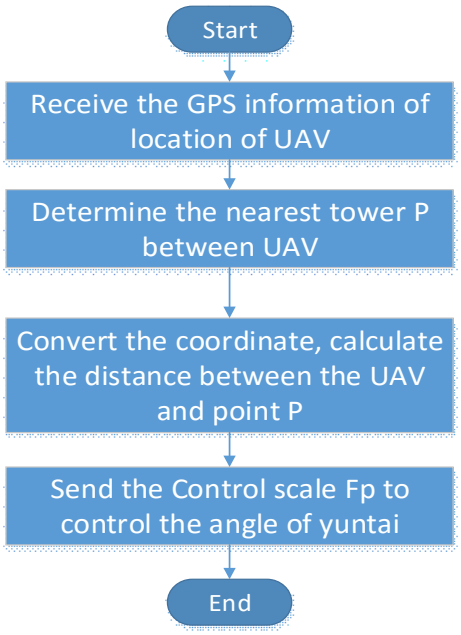

Figure1. *Flow chart of tower tracking algorithm for power transmission line inspection based on UAV*

The Figure.2 shows the Flow chart of line tracking algorithm for power transmission line inspection based on UAV.

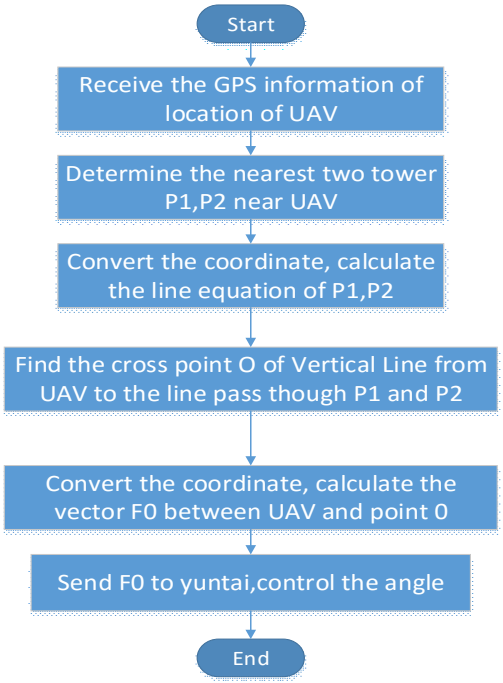

Figure2. *Flow chart of line tracking algorithm for power transmission line inspection based on UAV*

Multi UAV

Unmanned aerial vehicle (UAV) flight mainly depends on global positioning system (GPS) and preset route to achieve navigation, and adjust the specific path according to the field of vision of the imager. Therefore, before each operation, UAV needs to download the position of each tower, transmission line trajectory and other information. In order to ensure flight safety, flight constraints need to be superimposed in real time according to the actual situation [32].

The coordinated flight of two planes in traverse inspection will achieve flight synchronization based on multi-agent consistent coordinated control algorithm in pilot-follower mode, and take reasonable obstacle avoidance path. And mean while path planning algorithms is used to ensure flight safety.

Line Inspection Robots

The line inspection robots are complex system, the demands for mechanic are: a) it can move along the power line and can climb the slop. b) it can avoid the obstacle; c) it has small volume and light weight, d) it has security performance [31][33].

Its main part includes mechanic structure, the control system, the detection system. Its control system normally is distributed computer control system, often use plan control or direct control structure. Its detection methods include the video detection, the infra detection, the wireless spectra analysis technology and so on.

Its key technology includes video scan, navigation technology, and so on.

Numerical Weather Prediction and Forest Fire Modeling

Forest Fire Modeling

The power outage accidents of transmission line happened more and more frequently because of forest fire disasters, which seriously affected the safety and stability of the grid. Forest fire risk the transmission line is becoming an important research topic for disaster prevention and mitigation of grid.

There are several main reasons for flashover of transmission lines under mountain fires. (1) Air thermal dissociation; (2) Decrease of local air density; (3) Increased conductivity; (4) Electric field distortion, contact discharge of particles [34].

The traditional means of mountain fire monitoring are artificial observation on the spot through the observation tower, aircraft cruise, cutting down transmission line isolation to prevent mountain fire. Now, from the view of monitoring perspective, mountain fire early warning technology can be divided into two categories: one is wide-area and global mountain fire monitoring technology, such as satellite remote sensing technology; the other is local and small-scale mountain fire monitoring technology, such as local sensor network technology[34].

Monitoring Principle of Satellite Remote Sensing Technology

The blackbody temperature T is inversely proportional to the radiation wavelength λ_{max}. The higher the temperature, the shorter the radiation wave length. Infrared remote sensing judges the temperature of an object by detecting the radiation wavelength of the object[34].

$$T \times \lambda_{max} = 2897.8 \tag{14}$$

The infrared detector is installed on the satellite or aircraft to monitor the hot spots on the ground in a large area. The processing method is analyzed as below: Fixed threshold method, brightness temperature vegetation index method and context method are suitable for NOAA/AVHRR, while absolute fire identification method, MODIS context fire identification method, three-channel synthesis method and inter-class variance method are suitable for EOS/MODIS.

Micrometeorological Data

The season, time period, intensity and spread of mountain fires are closely related to the changes of meteorological elements, such as the evolution of atmospheric circulation, weather changes and climate anomalies. There are many meteorological factors affecting mountain fires, including temperature, wind, precipitation, relative humidity, sunshine, smoke, and their interaction [35].

Micrometeorological data are used to determine the Fire Meteorological Index (FWI), Forest Fire Risk Index (FFDI) and Forecast Forest Fire Range (FFBT).

Other Methods

Combining with the historical monitoring data of power grid, including meteorology, fire situation and line inspection, the influencing factors of mountain fire are found out in Paper [36], and a risk assessment model of transmission line mountain fire based on BP neural network is studied and put forward. The model can effectively predict the occurrence of mountain fires in transmission line corridors, and make an assessment, analysis and early warning of the trip of transmission lines due to mountain fires, so as to improve the ability to prevent and control emergencies, and provide strong support and guarantee for the safe and stable operation of transmission lines.

Icing, Wind Deviation Modeling and Numerical Weather Prediction

Icing Process

It is closely related to local micro-meteorology. The growth of conductor icing is affected by wind speed, icing time, precipitation, water droplet diameter, humidity and temperature. The automatic drop of conductor icing also requires certain environmental conditions, usually with the increase of ambient temperature, conductor temperature and ambient wind speed. It happens in the addition environment. Therefore, the micro-meteorological information collected by the micro-meteorological monitoring devices installed along the transmission line is worth exploiting and utilizing. The practical operation experience for many years shows that the structure of the micro-meteorological monitoring system is simple and reliable, the failure rate is low, and the data quality is high. It is feasible to realize the perception of environmental meteorological conditions and estimate the development trend of ice cover growth and de-icing jump [37].

The ice cover growth requires (1) The appropriate temperature is generally between -10~0°C; (2) the relative humidity is generally higher than 80%; (3) the suitable wind speed for the movement of water droplets in the air is generally 0~6 m/s; (4) the relative fixed wind direction, the angle between the wind direction and the line is between 45 ~135. Quick de-icing of conductors also requires certain meteorological conditions. Usually, it requires: 1) temperature rise, humidity decrease, usually temperature is greater than 0 °C, relative humidity is less than 80%. 2) wind excitation, wind speed continues to exceed 6 m/s, and wind direction and line angle between 45 ~135[34].

Wind Deviation and Typhoon

For transmission lines without windproof deviation measures, insulator strings or jumpers incline toward towers under the action of strong wind, which reduces the air gap between conductors and towers. Wind deviation flashover will occur when the insulation strength of the gap is insufficient to withstand the operating voltage of the system. Wind yaw flashover is the main factor causing trip of transmission line [38].

At present, the research on wind deviation of transmission lines mainly focuses on the calculation of maximum wind deviation angle of insulator strings. From the point of view of static equilibrium, the methods of solving wind yaw angle can be divided into rigid straight bar method and chord polygon method [39].

During typhoon, power system accidents occur frequently, and the damage of power facilities caused by disasters is greater. In addition, disastrous weather may lead to a longer time of power system repair, which seriously affects people's production and life. The traditional analysis method and statistical analysis method are mainly used in the research [40].

Faults Diagnosis, Line Parameter Measurement and Location Method

Common Faults of Transmission Lines

Lightning fault tripping has always been the major part of transmission lines. Lightning strike forms include direct strike, shielding strike, counterattack and inductive lightning strike.

Single-phase grounding fault is the most common type of fault in the operation of high voltage transmission lines. Most single-phase grounding faults occur in damp, rainwater and other harsh environments.

Short-Circuit Fault: When the HV transmission line in operation is affected by external forces and human factors, the breakdown of the conductor across the conductor and the insulator between the HV transmission lines will lead to the short-circuit fault of the HV transmission line.

Breaking Circuit: It is the most common fault. The most basic form of circuit breakdown is circuit failure. If there is no obvious trace of breaking, there will be gap, so there will be huge arc, which will cause the temperature of the high-voltage transmission line conductor to rise continuously, and cause fire or explosion in the power system, thus causing huge losses. In three-phase circuit, if one-phase circuit breakdown occurs, one may cause the motor to be burned down due to the lack of phase operation; the other may cause the three-phase circuit to be asymmetrical and the phase voltage to change, which will increase the phase voltage and cause accidents. In three-phase circuits, if the zero line (neutral line) is broken, the single-phase load will have a greater impact [41].

Line Parameter Measurement

The analysis and calculation of parameters of single-circuit transmission lines classified by single-circuit transmission lines and multi-circuit parallel transmission lines need to consider the coupling between self-parameters of phase conductors and three-phase conductors of this circuit line.

Because of its symmetry, the three-phase parameter model in practice can be decoupled into a single-phase circuit model. In engineering, transmission lines often measure their parameters in the way of three-phase symmetrical arrangement, which is also the practical practice in current engineering [8].

Conclusion

As the discussion in this paper, the challenges of power transmission line monitoring mainly result in three mainly domain.

First, to ensure the power transmission line work normal or decrease the loss under harsh and accidents, the video (or infra) surveillance system and technology, the digital imaging process technology, and the communication technology, should be developed. For example, the deep learning, the AI, the engineering application of remote or the satellite surveillance are challenges in these fields.

Second, as the additions of these surveillance system, the macro weather detection, the icing, typhoon, the wind direction precise modeling and prediction are the second challenge in this fields. For example, the big data, the IOT and the combining the related advance technology are time critical things in these fields.

Third, develop and extend the application fields of the UAV and line inspection robots(or other robots) using in transmission line monitoring are also the challenges in these fields.

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