Computer Vision based Automatic Power Equipment Condition Monitoring and Maintenance: A Brief Review

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Abstract—**In recent years, with the progress of science and technology, network communication technology, information processing technology, artificial intelligence technology, big data technology, navigation technology, power electronics technology and other rapid development, for the development of highly intelligent with independence. The autonomous navigation technology, which integrates computer vision, artificial intelligence, sensor fusion and other disciplines, will provide technical support for the practicality and popularization of the new type of power inspection robot. On the other hand, using robots instead of manual inspection is bound to be the future development direction. Research and development of substation inspection robot with autonomous navigation ability can sense the substation road environment through its own sensor system, plan the driving route and control the vehicle to reach the predetermined destination, which can greatly improve the inspection efficiency of the robot, broaden its operation range and improve the efficiency of the robot inspection To improve its working ability, this will make the power inspection robot to the practical direction of a big step forward.**

Keywords-Computer vision; Condition monitoring; Sub-station equipment;

I. INTRODUCTION

Modern society relies more and more on power, and the requirements of power grid monitoring, inspection and maintenance are higher and higher. No matter short-term or long-term blackouts, the impact on a country or enterprise may be catastrophic, which will lead to the shutdown of enterprises and the paralysis of key infrastructure functions [1]. From [2], a 30-minute blackout in the United States would cost large and medium-sized industrial customers an average of $15709. Therefore, power companies need to regularly detect, inspect, and maintain the power grid to prevent possible power failure. The traditional methods used to check the power network are field operation and aviation operation [3]. Regularly or in case of emergencies, such as after storms, hurricanes, and earthquakes, fieldwork teams shall be dispatched to observe the power line with binoculars on foot or by helicopter, sometimes with the help of infrared (IR) and corona detection camera [4]. Two methods are more common because they can cover all kinds of common faults such as power line components and the power line itself. However, the above methods have obvious defects, such as slow walking inspection, labor-consuming and detection efficiency affected by the experience of the staff; helicopter inspection can be difficult to be adopted in practice.

In the past few years, many scholars have done a lot of research, through the use of helicopters, flying robots or climbing robots and other machine vision assisted workers to check and detect. However, much research effort has been made related to power inspection based on machine vision. In [5], the authors studied the application of machine vision in power line detection. The application of the survey includes power line detection, insulator detection, power line corridor maintenance, and tower detection. The author points out that machine vision seems to be one of the most important technologies of power line detection based on automatic vision because inspection robots or UAVs not only need it for navigation and control but also fault determination and analysis. To comprehensively summarize the feasibility and challenges of power line inspection based on machine vision, many existing solutions are exploited and examined.

The fusion characteristics and requirements of autonomous operation of the flying robot are as follows:

(1) Perception ability of complex unstructured environment: flight robot's understanding of the working environment situation is based on the perception and recognition of unstructured environment features. Random changes of unstructured environmental factors greatly increase the difficulty of environmental perception. The high reliability and strong real-time perception ability of large-scale complex environments is the premise of autonomous operation.

(2) Airborne autonomous navigation, decision-making and control capabilities: the flight robot has high mobility, and can realize stable and reliable autonomous flight, precise attitude control in local range, and task adaptive decision-making according to the operation task without relying on external instructions and equipment support. It has flexible autonomy and adaptability to a complex environment.

(3) Intelligent fusion and learning adaptability: the dynamic randomness of unstructured environment leads to highly complex decision space in the autonomous operation of a flying robot. It is necessary to make full use of knowledge driven machine intelligent fusion and learning ability to adapt to unexpected and complex situations, to realize real-time accurate decision-making and efficient and reliable operation of a flying robot.

In recent years, due to its simple mechanical structure, high safety, high mobility and low cost, the

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four-axis rotor flight robot has attracted extensive attention. By carrying different types of sensors and detection devices, it can realize close observation and detection of targets. It is very suitable for large-scale inspection of energy infrastructure (transmission lines, photovoltaic power stations) in a complex environment.

The paper has the following sections: the study firstly summarizes the existing power line inspection methods and describes the advantages and disadvantages of each method. Next, it summarizes the automatic inspection tasks which are suitable for machine vision. Then, the paper summarizes the data sources of machine vision inspection and points out the applicable tasks of various data. Finally, from the two aspects of navigation and detection, this paper summarizes the current automatic power line inspection system based on machine vision.

II. COMPUTER VISION ENABLED SUBSTATION INSPECTION SOLUTIONS

This section overviews the recently published inspection methods based on the machine vision. The following is divided into two parts. The first part summarizes the method of UAV patrol navigation based on machine, including the method based on power line navigation and the method based on power line pole navigation. The second part is devoted to the UAV inspection and detection methods based on machine vision. These methods may realize the automation of three main UAV inspection tasks: ice detection and thickness measurement, vegetation occupation monitoring, and power line component mapping.

A. Computer Vision-based Navigation Technology

There are three common UAV communication methods in automatic power line inspection: based on GPS route point, based on power line navigation and based on power line pole navigation [6]. The first method has been widely used for decades, and the other two methods have received more and more attention recently because of their applicability in visual reconstruction.

In [7], a method for power line detection in aerial images is proposed. Firstly, a filter based on a pulse coupled neural network is used to remove the background in the image. Then, the Hough transform is used to detect the line. Finally, K-means clustering is used to eliminate false linear objects. In [8], a similar three-step method is also used to detect power lines. First, the linear objects in the background are enhanced by a double-sided filter. Then, the Radon transform is used to detect the line. Finally, parallel line constraints are used to identify power lines. The work in [9] developed a solution to detect overhead power lines from UAV video images. The fuzzy C-means (FCM) clustering algorithm is used to distinguish the detected power line from other objects by taking the length and slope of the detected line as the feature application vector. Finally, remove useless information.

In [10], an improved Bayesian classifier is proposed for power line detection. The traditional Bayesian classifier was improved by using the prior information obtained by Hough transform to determine the prior probability and the posterior probability. In the study [11], the Bayesian classifier is used to detect power lines in helicopter collected images. Firstly, the Hough transform is used to improve the Bayesian classifier to classify pixels. Then, through the component analysis, the small component (the pixel with the wrong classification) image is deleted from the classification. In [12], a new method of power line detection based on circle search (CBS) is proposed. Firstly, canny and steerable filters are applied to the segmented power line image captured by UAV. Then, based on the CBS method, it detects whether the power line comes from the adjacent segmented image.

The authors in [13] presented a method for detecting and tracking power lines in complex environments where the power line is tracked by the Kalman filter in Hough space. In [14], the authors proposed a method to detect and track power lines in a complex environment. Firstly, four directions of the input image are filtered by using a certain number of filters. Next, the image is transformed into a binary image, and then an image morphological operation is used to remove unnecessary objects. Then, a Canny edge detector and Hough transform are used to detect the power line. Finally, the detected power line is tracked by a universal joint system. The study in [15] also proposed a method to detect and track power lines. Firstly, the contrast of the input image is enhanced. Then, the edge graph is formed by gradient calculation. Then, the aggregate Hough transform (AHT) is formed by calculating the Hough transform from cluster points in the Hough transform. Finally, the power line is tracked and acquired at the point of AHT.

B. Computer Vision-based Inspection Technology

In [16], a method for detecting transmission line dampers is proposed. Firstly, a threshold method is used to segment the damper from the inspection image. Then, the damper is detected from the segmented image based on the improved Snake method and Hessian matrix. The faster R-CNN (local convolutional neural network) object detection framework and vgg16 model were also proposed to detect terminal failure devices (DEBCS).

The method based on hog feature and MLP neural network can be used for detecting and classifying power line towers. First, a sliding window method is used to train the level 2 MLP for background foreground segmentation. Then, multi-level MLP is used to train and identify four different power towers. Also, a method was exploited to identify insulators from aerial images. The support vector machine (SVM) model is used to train the features extracted by the Gabor filter for insulator classification. In the literature, the robust algorithm for insulator detection in aerial images was also adopted. the multi-scale and multi-feature (MSMF) descriptors were proposed to represent local features. The spatial order feature (SOF) is used to improve the robustness of the algorithm. Finally, the region of the insulator is determined by the matching strategy. The solution for detecting lightning damaged cables was proposed. First of all, the brightness of the cable is statistically analyzed, which is based on the average cable brightness and its standard deviation to mark the detection arc. Then, the cutting line is detected by using the shape information obtained from the comparison between the real cable profile and the ideal cable profile.

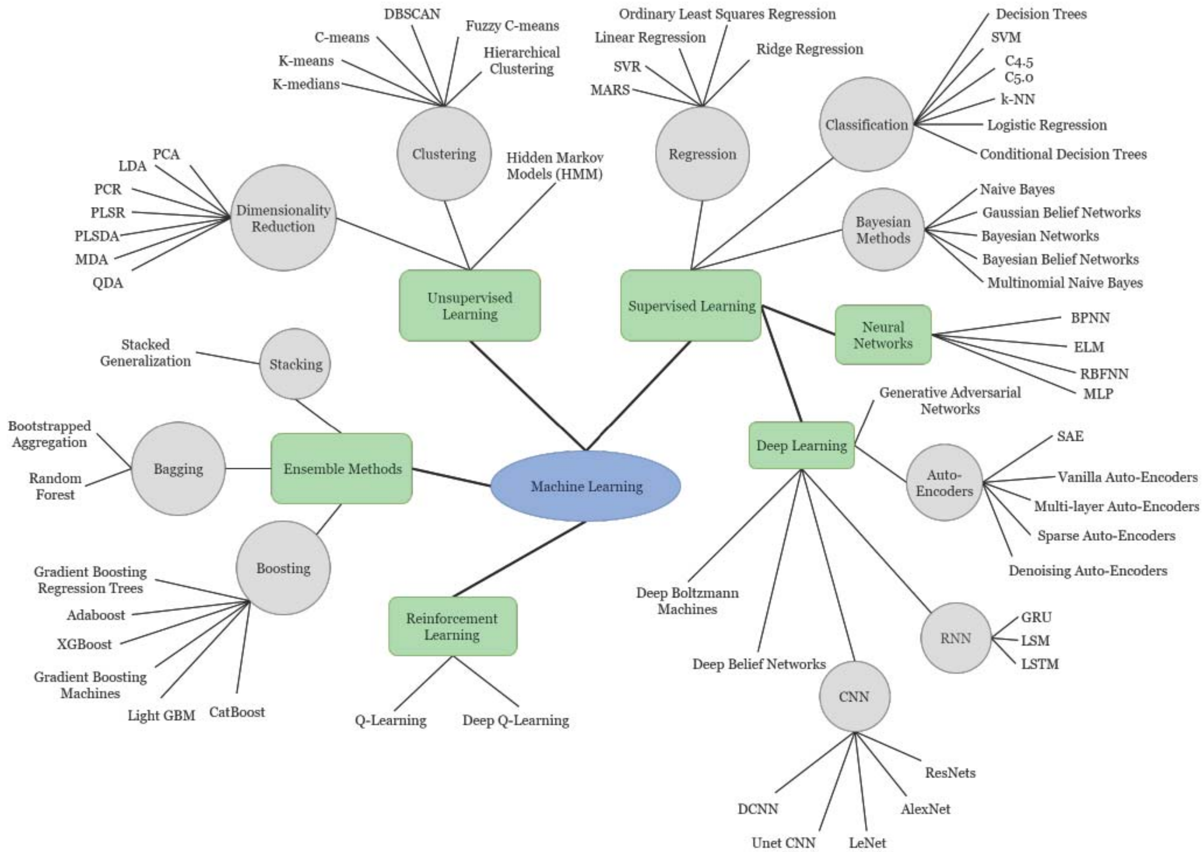

Figure 1. An overview and classification of various machine learning techniques.

III. ALGORITHMIC MODELS OF THE EQUIPMENT CONDITION ANALYSIS

An overview of the state-of-the-art machine learning is illustrated in Fig. 1. Currently, machine learning techniques have gained popularity in smart energy systems during the past few years and researchers have been exploring a range of machine learning methods to various of the smart energy systems and distributed energy systems challenges discussed in the previous section. These are highly data-dependent techniques that make use of the available data to perform various operations such as prediction, clustering, classification, regression, recognition. Large scale energy infrastructure inspection environment has typical dynamic unstructured characteristics, which brings new and more urgent technical challenges to the autonomous operation of flight inspection robot

First of all, the working environment is complex and the interference is serious: the natural environment and landform of the power transmission corridor and photovoltaic power station change with the seasons, and the background of aerial images is complex and changeable; the inspection objects (towers, fittings, photovoltaic modules, etc.) are close in color with the complex background images, and the detection targets are not prominent in the inspection images of flying robots, and the interference is serious, and the target detection and fault recognition are also involved Don't be too difficult.

Secondly, it is difficult to achieve accurate and stable flight attitude control: flight robots usually have small self-weight, high signal-to-noise ratio, poor wind resistance, and environmental factors have a great impact on its flight stability. The quadrotor flight robot is an underactuated system with six degrees of freedom and four control inputs. It has the characteristics of nonlinearity, multivariable, strong coupling and weak anti-interference ability. It is worthy of further research to realize stable flight attitude control in the "high-risk application" of autonomous inspection operation.

Finally, it is difficult to express and identify the fault characteristics of the inspection object: there are many fault types of equipment components, the image morphology is changeable, there is no fixed mode, the feature performance is not clear, and the location is uncertain. Traditional image processing and machine learning methods mainly aim at the closed static environment (data distribution is constant, sample category is constant, sample attribute is constant, and the evaluation target is constant). However, due to the complex environment and changeable scene of flying robot inspection, traditional methods have many difficulties, so a robust machine learning method is needed in open environments.

IV. Conclusion And Discussion

Due to the continuous connectivity provided by IoT and explosive amounts of data being generated by the smart devices at every entity of smart grids, the need of proper data analysis, handling, and the associated security have also emerged which can be addressed effectively with the use of machine learning techniques in various aspects of smart grids. This paper discusses the research conducted on machine learning applications in smart grids and, after a comprehensive literature survey, puts forwards some prospects in the light of challenges identified in the literature of computer vision-based applications.

According to the analysis of the research literature, some research achievements have been made in this field at home and abroad in the early stage, but there are still some scientific challenges to be addressed in the future:

(1) the inspection image samples of machine vision are incomplete and unbalanced, and the expression reliability and robustness of inspection target and operation environment characteristics are insufficient;

(2) the visual positioning and map building methods of flying robot still rely on The manually set feature points or simple features can not be applied to the dynamic unstructured complex inspection operation environment;

(3) the flight stability control method suitable for the inspection operation of flying robot is not perfect, which can not guarantee the whole process autonomous flight and reliable operation in complex aerodynamic environment.

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