CIM/G graphics automatic generation in substation primary wiring diagram based on image recognition

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Abstract—With the further development of smart grids, people put forward more requirements for the intelligent level of the dispatching automation system, and the demands for unified substation standard, realization of unified association and sharing of models, data and graphics are gradually increasing. Relying on the CAD, PDF and other graphic format files of the substation, we use grid recognition technology based on image recognition and OCR to identify standard primitives, topological connections, device names and other information, and automatically draw standard CIM/G files. For the identified CIM/G file, we use related technologies of natural language to associate the primitives in the CIM/G file with the model data, and form the overall solution for a grid substation wiring diagram primitive recognition, text recognition, topology recognition, model association. We also construction substation graphic file recognition and construction system based on the image recognition to support the maintenance of the substation graphic inside the control center. Through the system deployment application, it is verified that the method can effectively reduce the workload of manual maintenance and improve work efficiency.

1. INTRODUCTION

With the development of smart grid, the maintenance and sharing technology of the graphic information of the main and sub-stations is relatively mature. Many manufacturers and scientific research institutions are committed to establishing and promoting unified substation standards to achieve unified association and sharing of models, data, and graphics. With the further development of the smart grid, more requirements are placed on the intelligence level of the dispatch automation system. It is necessary to use artificial intelligence technology to change the traditional working methods and modes, so as to adapt to the development needs of the smart grid, and the efficiency of regulation, operation and management can be improved [1].

At present, the power system graphic description specification, which is based on the CIM/G technical standard, realizes the maintenance of the attributes and topological connection relationships of the primary wiring diagram of the substation, supports the global storage and sharing of the grid graphics within and between the control centers, facilitates the realization of the functions of plant stations graph generation and remote browsing, and provides technical support for horizontal integration and vertical
penetration of power grid dispatching services. However, the maintenance of the CIM/G graphics of the substation is mainly done manually. According to the CIM/G grid graphics description specification of the dispatching automation system, the staff uses the wiring diagram editor to perform graphic maintenance to realize the correlation of the model data. Although an automatic diagramming method based on the data model has been proposed, there still are problems such as chaotic line connection, even serious bending and intersection, and the manual maintenance workload is large and the efficiency is low.

At present, many research institutions and manufacturers have done a lot of research work on the identification and automatic mapping of power grid graphics. In the automatic generation of single-line diagrams of transmission and distribution networks, some manufacturers have also studied the automatic layout algorithm of wiring diagrams. Reference [2] proposed that the substations and feeders in the power grid should adopt different layout ideas based on CIM model data and their characteristics; the graphic wiring in reference [3] is based on traditional circuit channel routing algorithms; the method in reference [4] based on the characteristics of power grid flow chart, which generates the screen coordinate position of the plant station through the simulated annealing algorithm and the automatic generation method of the line pattern between the plant stations, is not suitable for the wiring diagram of the primary equipment in the substation; reference [5] with Oracle Spatial’s network analysis function achieved generation; reference [6] analyzed and summarized the graphical interface specifications, creates primitive templates and layout methods as styles, and built a style library. When in use, we only need to pick the style from the style library, avoiding repeated drawing of primitives. References [2-5] all rely on existing data models, use different automatic layout algorithms based on business scenarios, and do not make full use of the design drawings provided by the design institute, including primary system equipment and wiring methods, etc.; reference [6] improves the existing drawing tools, but manual drawing is still required. In summary, the current automatic drawing technology based on model data is not very practical, the equipment connection line is seriously deformed, and the manual correction work in the later period is relatively large. In combination with artificial intelligence technology, using the CAD or PDF graphics of the substation provided by the design institute to automatically construct a wiring diagram has not yet been carried out at home and abroad.

This paper based on a large number of substation CAD, PDF and other graphic format files existing in the control center, and used machine learning-based grid pattern recognition, OCR and other technologies to identify standard primitives, device names, straight lines and other information, and automatically drew the initial CIM/G file with equal attributes including device types and coordinates, and then for the identified CIM/G file, we used natural language-related technologies to correlate with model data, which can transform the working mode of automation personnel, reduce maintenance pressure, and improve maintenance efficiency.

2. CIM/G MODEL AND DESIGN DRAWING SPECIFICATIONS OF POWER SYSTEM
The CIM/G standard includes two file formats, including definition files and graphic files. Among them, the definition file describes the graphic element library, dynamic display style library and coloring configuration library. The graphic file describes the element description and public information reference of the plant and station diagram, power flow diagram and other graphics [7].

The main four steps of generating CIM/G graphics automatically based on the CAD or PDF design drawings are as follows: First, convert the CAD or PDF file into a picture format according to the pre-defined format requirements, and perform preprocessing operations such as grayscale conversion; the second is to identify the device primitives and labels in the picture; the third is to identify the topological relationship of the wiring diagram and correct the position of the device primitive according to the topological relationship; the fourth is to generate CIM/G files according to the pre-set CIM/G file label library. The overall frame diagram is shown in Figure 1.
The design drawings of substations follow certain design specifications, and many countries will use the International Electrotechnical Commission IEC617 standard as a basis when formulating electrical design drawings standards. In 1987, China issued the "Notice of Promoting National Standards for Graphic Symbols for Electrical Drawings in the National Electrical Field", which promoted the integration of Chinese electrical technical documents with international standards.

Through graphics recognition, OCR and other related technologies and substation design drawing specifications, the grid structure information and power equipment measurement information in the primary wiring diagram of the substation can be completely displayed, which meets the demand of graphic integration maintenance and real-time sharing between the control centers at all levels, and between the control center and the substations.

3. TAG RECOGNITION BASED ON DEEP LEARNING OCR

The primary wiring diagram design diagram of the substation contains three types of information, including text labels, device primitives, and connecting wires and busbars. In order to avoid the interference of text labels and device primitives on the spectrum detection, the text labels and device primitives need to be identified first, and then deleted from the graph to avoid interference with the final topology detection.

The purpose of label identification is to identify all the text information in the wiring diagram except the device and the connection line, and return the content and coordinates of these text labels. In this paper, CRNN's deep learning method is used to extract the label content in the picture. It mainly includes the following steps:

- CRNN network model construction;
- Deep learning network model training;
- Use appropriate methods to evaluate the trained model;
- Use the trained model to extract the text information in the picture.
CRNN is a combination of CNN and RNN, and its structure is shown in Figure 2.

From the bottom up, the CRNN network contains three layers, namely conv layers, recurrent layers, and transcription layers. At the bottom of CRNN, conv layers automatically extract a feature sequence from each input image. At the top of the convolutional network, we build a recurrent network to predict the feature sequence of each frame output through conv layers. The transcription layer translates the prediction of each frame into a label sequence. Although CRNN consists of different network structures, it can use a loss function for jointly training [8].

In the CRNN model, the components of conv layers are constructed from the conv layers and max-pooling layers used in a standard CNN model (removing FC layers). Such components are used to extract a serialized feature representation from an input picture. Before feeding to the network, all pictures need to be normalized to the same height. Next, a sequence of feature vectors will be extracted from the feature maps. In particular, each feature vector of a feature sequence is generated by column-by-column on the feature maps, which means that the i-th feature vector is the concatenation of the i-th column in all maps. In our setup, the width of each column is registered as a single pixel.

On top of conv layers, a deep bi-RNN network is constructed. The recurrent layers can predict a label distribution $y_i$ for each frame $x_i$ in the feature sequence $x=x_1, \ldots, x_T$.

In the process of network model training, relying on the limitations of nouns in power grid substation, we use the specified font to generate a picture font to generate sample data, such as "busbar", "main transformer", "standby transformer", etc., to support CRNN network model training.

The training data set is defined by $X=\{I_i, l_i\}$, where $I_i$ is the training picture and $l_i$ is the label sequence of ground truth. The objective function is -log-likelihood that minimizes the conditional probability of ground truth:

$$O = -\sum_{l_i \in X} \log p(l_i | y_i)$$

(1)

Among them, $y_i$ is a sequence generated by $I_i$ through recurrent layers and conv layers. The objective function calculates a cost value from a picture and its ground truth label sequence. Therefore, the network can perform end-to-end training on (images, sequences) pairs, eliminating the process of manually labeling all independent components in training images.

**Figure 2.** CRNN structure diagram

4. DEVICE PRIMITIVE RECOGNITION BASED ON MULTI-SCALE TEMPLATE MATCHING

In terms of device primitive recognition, we can use two methods to detect, one is to use computer graphics algorithms to recognize the image, and the other is to use machine learning algorithms to train the model, and then use the model to complete the recognition of specific objects in the image.
Using computer graphics for image detection needs to meet certain conditions, this method does not need training samples, but requires that the image to be detected is less noisy, that is, the image to be detected is standard and the size of the contour is the same. The machine learning algorithm has a high requirement on the data volume of the training samples. The problem that is suitable to be solved is that the image to be detected is noisy and the scale contour of the object to be recognized varies. The format of CAD graphics in power system is clear, the style of each icon is clear, and the noise interference is 0, which is very suitable for the identification of specific objects using the method of computer graphics.

Template Matching is the most basic and most commonly used matching method in image processing, and its principle is to match based on the gray value of the template and the image [9]. The template matching methods commonly used in OpenCV include variance matching method, correlation matching method, and so on.

In the process of designing and drawing the primary wiring diagram of the substation, the size of the device primitives will change according to the needs. In this case, because the size of the template differs greatly from the size of the target in the original image, the traditional template matching algorithm can only recognize a part of the area in the original picture. In order to solve this problem, this paper proposes a multi-scale template matching algorithm, the specific steps are as follows:

• Template image preprocessing, read the template, grayscale processing and edge detection to it;
• Pre-process the pictures to be matched, read the pictures to be matched;
• Perform edge detection and template matching to obtain a circumscribed rectangle;
• According to the result, update the position of the template in the test picture; obtain the matching result and update the matching position information;
• Display matching results.

In the template matching method, this paper uses the normalized correlation coefficient matching method (CV_TMCCOEFF_NORMED), its principle is as follows:

$$R(x, y) = \frac{\sum_{x',y'}(T'(x',y')I'(x+x',y+y'))}{\sqrt{\sum_{x',y'}T'(x',y')^2\sum_{x',y'}I'(x+x',y+y')^2}}$$  \hspace{1cm} (2)

Where T is the template picture matrix and I is the picture matrix to be matched.

After the device primitives and labels are identified, in order to avoid interference with the topology identification of the wiring diagram, all device primitive information and label information need to be deleted from the original image, which only retains straight line information on the way, and then further wiring diagram straight line identification was carried out.

There are three types of existing straight line detection algorithms, namely Hough straight line detection algorithm, Freeman straight line detection algorithm and inchworm creep algorithm, among which Hough straight line detection algorithm is the most widely used [10]. The Hough straight line detection algorithm uses the principle of coordinate domain transformation. This algorithm has strong anti-interference ability and is insensitive to noise in the image. It is very suitable for straight line recognition of substation primary wiring design drawings.

In this paper, the Hough transform straight line detection method is used for topology recognition. The specific steps are as follows:

• Convert the image to grayscale;
• Denoising (Gaussian kernel);
• Edge extraction (gradient operator, Laplace operator, canny, sobel);
• Binarization;
• Map to Hough space. Prepare two containers, one to display the overview of hough-space, and one array to store the value of voting, because the voting process often has a certain maximum value exceeding the threshold, which can be up to several thousand, grayscale images cannot be used directly to record voting information;
• Take the local maximum value, set the threshold, and filter the interference straight line;
• Draw straight lines and calibrate corner points.
The advantage of Hough line detection is that it has strong anti-interference ability, is insensitive to the missing parts of lines in the image, noise and other non-linear structures that coexist, can tolerate the gaps in the description of feature boundaries, and is relatively unaffected by image noise.

5. TOPOLOGICAL RELATIONSHIP DETECTION AND DEVICE PRIMITIVE POSITION CORRECTION

After the straight line detection is completed, the device primitive information, label information, and straight line information have been obtained at this time, and then the topological relationship detection is performed based on all the above information. The detection of the topological relationship of the primary wiring diagram of the substation is divided into two steps. The first step is to associate the device name with the device, and the second step is to associate the connection relationship between the devices.

In the process of associating the device name with the device, for each device, we need to find the label closest to its location. The distance between the label and the device is based on the Euclidean distance between the two coordinates, specifically:

\[ \rho = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \]  

(3)

Where \( \rho \) is the Euclidean distance between the device coordinates \((x_1, y_1)\) and the label coordinates \((x_2, y_2)\).

According to the Euclidean distance, all candidate tags are obtained. For the candidate tags, the device type and the content of the tag are compared, and finally an accurately matched tag is obtained, which is matched with the device.

Based on the drawing specifications of the substation design drawings, the naming of different types of equipment follows certain characteristic rules. For example, the names of transformers include "#1 main transformer", "1# main transformer", "1# transformer", "2# transformer", etc. The names of busbar are "#4", "#5", "#4 busbar", "#5 busbar" and so on. These names are all short text. In this paper, a Naive Bayes classifier is used to classify the label and mark the type of device that it identifies.

The classification process of the Naive Bayes classifier is shown in Figure 3.

![Figure 3 Short text Bayes classifier](image)

Among them, feature selection is to select feature words suitable for classification. Typically, mutual information is used to select short text features, as shown below:

\[ MI(t) = \sum_{i=1}^{\left|C\right|} P(c_i) \log \frac{P(t|c_i)}{P(t)} \]  

(4)

\(|C|\) represents the number of text types, \(P(c_i)\) represents the probability of the i-th type of text appearing in the training text set, \(P(t)\) represents the probability of the word t appearing in the training text set, \(P(t|c_i)\)
represents the probability of $t$ appearing in the $i$-th text. The greater the MI, the greater the co-occurrence of words and genres.

A typical Bayesian classifier (Naïve Bayes) is as follows:

$$P(c_i|d_j) = \log P(c_i) + \sum_{l=1}^{D} \log (1 - P_{kl}) + \sum_{k=1}^{D} W_k \log \frac{P_{kl}}{1-P_{kl}}$$

(5)

Given a binary text vector $d = (W_1, W_2, ..., W_0)$, $W_i = 0$ or 1. If the $i$-th feature appears in the text, $W_i = 1$, otherwise $W_i = 0$. Let $P_{ki} = P\{W_k|c_i\}$, $P\{\cdot \}$ denote the probability of occurrence of {·} [11].

After obtaining the device type identified by the label, we compare it with the real device type. If they are the same, it means that it meets the requirements, and the label can be matched with the device.

6. CONCLUSION

This paper uses CAD, PDF and other graphic format files of the substation, and uses machine learning, image recognition and other technologies to form a method of automatically generating CIM/G files. Compared with the automatic layout method, the CIM/G file generated by this method is more accurate, making full use of the design drawings and related information provided by the design institute to avoid the loss of information. According to the results of CIM/G generation in a province, it can automatically identify more than 90% of the primary wiring diagram of the substation, saving more than 75% of the time of the automation personnel, greatly reducing the maintenance pressure of the automation personnel, and improving the maintenance efficiency of the primary wiring diagram of the substation.

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