Research on substation perimeter isolation based on phased array radar and multi-video fusion technology

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Abstract: This paper presents a perimeter isolation technique based on phased array radar and multiple video fusion perimeter isolation technique, aiming at the disadvantages of high false alarm rate and easy to be affected by the environment of traditional perimeter security system of substation. It uses the advantages of phased array radar, such as long detection distance, high anti-jamming ability, fast detection speed and high accuracy, and combines the multi-camera collaborative recognition technology with the multi-video data fusion technology as the core to realize the effective fusion of mobile target recognition information.

1. Instructions

Along with unceasing progress of automation level of the substation and unceasing application of unattended substation, the security and the information request of the substations also unceased enhance. Perimeter isolation is the first line to prevent intruders from climbing and crossing and to ensure security. It is the most important link to realize closed-loop management of security prevention and it’s very important and indispensable to prevent invasion.

The existing perimeter target detection technology has experienced the first generation of target detection technology that is based on visual information and the second generation of target detection technology that is characterized by non-video signal analysis and detection[1]. The first generation of anti-intrusion target detection technology is mainly based on video monitoring technology. As a visual information perception and acquisition method of a scene, video monitoring technology requires manual full-time monitoring, so that monitoring personnel are easy to get tired and cannot give an alarm in advance or in real time. More often than not, it acts as an afterthought. The second generation of target detection technology includes high voltage electric pulse fence, active infrared correlation technology, tension fence, microwave sensor, static electric field sensor, leak cable[2]. They all belong to the target detection technology that based on the analysis of characteristics of signal. While they solved the problem of artificial monitoring and real-time alarm, there are still some disadvantages, such as high false alarm rate, high missing report rate and significantly affected by environments.

This paper presents a perimeter isolation technique based on phased array radar and multiple video fusion perimeter isolation technique. The phased array radar is regarded as the core sensor of the perimeter system, and the electronic system based on visual information is regarded as the detection sensor of the perimeter system. Multi-sensor fusion is divided into three levels: data fusion between detection sensor and core sensor, feature level fusion based on detection sensor and core sensor, and
decision level fusion between detection sensor and core sensor. In this way, the distance, angle, speed and other parameters of the target can be checked comprehensively and quickly, and the linkage can be carried out with video.

2. Research on phased array radar technology

2.1 Fundamentals of phased array
Phased array antenna\[^{[3]}\] is composed of many radiation elements, the feed phase of each element can be flexibly controlled and change the wavefront. The array elements of phased array antenna are generally 100-10000, each element is followed by a controllable phase shifter. Changing the phase shift of each phase shifter will change the relative feed phase between the array elements and the wavefront direction of antenna radiated electromagnetic waves. The schematic diagram of the array antenna is shown in Figure 2.1 below:

![Figure 2.1. Schematic diagram of array antenna](image)

The spacing between the antenna array elements is d, and the angle between the target azimuth and the normal vector of the antenna array surface is $\theta$. The echo phase difference of adjacent array elements is $\psi$, the wave path difference is $d \sin \theta$, and the phase difference caused by the wave path difference is:

$$\psi = \frac{2\pi}{\lambda} d \sin \theta \quad (2.1)$$

Consider the distance, suppose n-antenna elements are evenly spaced, constant amplitude supply, the sum of the radiation field vectors at some point in the direction $\theta$ is:

$$E(\theta) = \sum_{k=0}^{N-1} e^{i\psi} \quad (2.2)$$

If the supply phase difference of each array element is 0, the above formula can be used to study the direction diagram of array antenna. Use the geometric series summation formula, euler formula and formula 2.2, we get normalized antenna pattern:

$$F_a(\theta) = \frac{\sin \left( \frac{\pi \theta}{N \sin \frac{\pi \theta}{d \sin \theta} \right)}{N} \quad (2.3)$$

$F_a(\theta)$ calls array factor or array factor. If the antenna elements are not uniformly radiating into space at all angles, the direction diagram is $F_a(\theta)$, the array direction diagram becomes:

$$F(\theta) = F_a(\theta) F_e(\theta) \quad (2.4)$$

Where $F_e(\theta)$ is called the matrix factor.

2.2 Phased array antenna scanning
The relationship between supply phase difference and equivalent wave path difference is shown in figure 2.2 below:
When the supplying phase of the array antenna in the figure decreases according to $\psi_0$, the beam direction is $\theta$. By changing $\psi_0$, phased array scanning can be realized. The antenna direction is shown as follows:

$$F_\psi (\theta) = \sin \left[ \frac{2\pi d}{\lambda} \sin \theta - \sin \theta_0 \right]$$

(2.5)

The condition that no grating flap is satisfied is:

$$\frac{d}{\lambda} < \frac{1}{1 + |\sin \theta_0|}$$

(2.6)

3. Research on multi-video fusion technology

Intelligent video surveillance system[4] not only needs to accurately extract moving objects from videos, but also needs to know some characteristics of objects, such as position, size, shape, histogram, speed and direction of motion, so as to analyze the behavior of moving objects and judge whether abnormal or suspicious behavior occurs. The data level fusion algorithm in this paper mainly fuses the position, color histogram[5] and speed of moving objects in multiple cameras. The overall structure is shown in Figure 3.1 below:

![Figure 3.1. Multi-video collaborative recognition system structure](image)

Each single camera starts from acquiring scene information, and first carries out target detection. In order to locate the target continuously, it is necessary to track the target accurately. This process needs
to utilize the feature information of the target. The trajectory and duration of moving target can be accurately acquired by target tracking. Finally, the moving target is identified and analyzed. The process is divided into three levels: the moving target detection in low-level, the target tracking in middle-level and the target recognition and analysis in high-level. At the same time, multiple single cameras do not work in isolation, but continue to fuse local information to achieve the goal of collaborative analysis.

Suppose there are N cameras in the monitoring area, and p represents a specific one, \(1 \leq p \leq N\). Suppose there are several targets in camera P, and the target set is denoted as \(O = \{O_1, O_2, \ldots, O_M\}\), i represent a specific target, \(1 \leq i \leq M\). Each new target is extracted and saved by the camera tracking it for the first time. In this paper, target position, size and speed are selected as the main features. It is assumed that target I of P in the camera is marked as \(q^p_i, v^p_i, h^p_i\). The target is first captured by a single camera and marked (position, shape, speed, color histogram, size). Suppose the unique feature vector \(T^p_i(h^p_i, s^p_i, w^p_i)\) of target I in camera P is obtained through data fusion of data layer, where \(s^p_i\) is the shape parameter and \(w^p_i\) is the target size parameter. Meanwhile, the unique feature vector \(T^c_d(h^c_d, s^c_d, w^c_d)\) of target d in camera c can also be obtained. Pattern recognition clustering analysis\[^6\] is adopted to achieve the handover of goals. By calculating the Bhattacharyya distance to measure their similarity, the formula is shown in 3.1:

\[
sim(h^p_i, h^c_d) = \frac{1}{1 - \sum_j \sum_j h^p_i(j) h^c_d(j) / \sum_j h^p_i(j) / \sum_j h^c_d(j)} \quad (3.1)
\]

If the target matches exactly, the value of this parameter is 0, or it is 1.

For the direction parameters, formula 3.2 is used to measure the similarity between them:

\[
sim(s^p_i, s^c_d) = \frac{1}{1 - (s^p_i)^2 + s^p_i s^c_d} \quad (3.2)
\]

If the targets are the same, the value of the similarity function is 1.

For the size parameters, formula 3.3 is used to measure the similarity between them:

\[
sim(w^p_i, w^c_d) = 1 - \left(1 - \frac{w^c_d}{w^p_i}\right)^2 \quad (3.3)
\]

Combined with the above formula, the comprehensive similarity degree function of the two moving targets is defined as:

\[
sim(T^p_i, T^c_d) = (1 - \sim(h^p_i, h^c_d)) \cdot \sim(s^p_i, s^c_d). \quad (3.4)
\]

Set the threshold \(T(0<T<1),\) if \(T < \sim(T^p_i, T^c_d) < 1\), it is considered that target i in camera P and target d in camera C are the same target, the target handover is completed.

On the basis of successful target handover, parameters of the same target in multiple cameras need to be fused to obtain a more accurate description of the target.

For one frame image, take the average position of the same moving target in multiple cameras as the accurate position of the moving target, then the accurate position \(q_i(x_i, y_i)\) of the \(i\)th target is:

\[
q_i = \frac{1}{N} \sum_{p=1}^{N} q^p_i \quad (3.5)
\]

Where:

\[
x_i = \frac{1}{N} \sum_{p=1}^{N} x^p_i \quad (3.6)
\]

\[
y_i = \frac{1}{N} \sum_{p=1}^{N} y^p_i \quad (3.7)
\]
In multiple monocular cameras, Gaussian distribution modeling and motion template algorithm\cite{7} are used to obtain the motion contour. The direction parameter $s^p_i$ of the target is obtained from the aspect ratio of the contour of the moving target, so the direction parameter of the fusion $i$th target is the Gaussian average of the target parameters in multiple cameras. That is:

$$s_i = \frac{1}{N} \sum_{p=1}^{N} s^p_i \tag{3.8}$$

The moving speed of a moving target can be measured by the ratio of the distance that the target moves against the time it takes to pass the distance. The distance the target moves is the length of the final position of the target relative to the initial position, so the velocity of eye I in camera p can be expressed as $v^p_i = s^p_i / t^p_i$, where $s^p_i$ and $t^p_i$ respectively represent the motion distance of the $i$th target in the $p$-th camera and the time taken to pass through this distance.

For the $i$th target in the $p$ camera, each m frame is used as a computing unit. Assuming that the first frame in which the moving target appears in the camera is frame $h$, in the first frame $m$, the moving distance of the moving target is $s^p_i h^m$, and the moving time is $t^p_i h^m$, then the moving speed of the target in this period is:

$$v^p_i h^m = s^p_i h^m / t^p_i h^m \tag{3.9}$$

By analogy, the remaining velocity can be obtained:

$$v^p_i h^m+2 = s^p_i h^m+2 / t^p_i h^m+2$$

$$v^p_i h^m+3 = s^p_i h^m+3 / t^p_i h^m+3$$

$$\vdots$$

$$v^p_i h^{(j-1)m} = s^p_i h^{(j-1)m} / t^p_i h^{(j-1)m}$$

$$v^p_i h^{jm} + (j+1)m = s^p_i h^{jm} + (j+1)m / t^p_i h^{jm} + (j+1)m$$

It can be concluded that the modified speed of the $i$th target in the $p$-th camera is:

$$v^p_i = \left[ v^p_i h^m + v^p_i h^m+2 + \ldots + v^p_i h^{(j-1)m} + v^p_i h^{jm} + (j+1)m \right] / (j+1) \tag{3.10}$$

Where $(j+1)m \leq n$, $n$ is the total frame number of video collected by the camera.

Using the method to obtain the moving velocity of the $i$th target in the other $n-1$ cameras, so the accurate speed of fusion of the $i$th target is:

$$v_i = \frac{1}{N} \sum_{p=1}^{N} v^p_i \tag{3.11}$$

Due to the different angles of multiple cameras and the different light intensity of different angles, the color histogram obtained locally varies to a certain extent. In this paper, the color histogram of a single camera is modified by integrating the color histogram obtained by different cameras. And the modified histogram can also be used as an auxiliary means of target tracking handover. Firstly, the color histogram equalization of the same moving target in multiple cameras is processed. The gray scale transformation function used in equalization selects the gray scale cumulative distribution function of image\cite{8}, which has the function of uniform gray scale stretching. Secondly, each equalized histogram is matched and fused to obtain the final accurate color histogram of the moving target.

### 4. Application in perimeter isolation of substation

The phased-array radar and multi-video fusion security warning system of substation mainly include the front-end phased-array radar and camera, computer network and wiring, back-end server and alarm management system. When the abnormality is determined, the acoustooptic alarm device in the
managements alarm area is triggered to feed back to the background monitoring general platform in the first time. The flow chart is shown in figure 4.1 below:

![Intelligent security system diagram](image)

**Figure 4.1. Intelligent security system**

After receiving the alarm, a variety of alarm information will be displayed on the plane, prompting the operation and maintenance personnel through voice, icon, etc., and the abnormal situation will be synchronously transmitted to the control center, to provide unified command and treatment of the on-duty personnel.

5. Conclusion
This paper presents a phased array radar and visual fusion technology to detect targets and achieve alarm. It can accurately identify all kinds of objects in the alarm area. It also has the great economic and environmental significance in solving the safety problem of substation.

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