Rapid Configuration Method for Inspection Object of Substation Inspection Robot Based on Hierarchical Map

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Abstract. This paper mainly focuses on the problem of time-consuming and labor-intensive configuration of existing inspection objects. A rapid configuration method for inspection objects of substation inspection robots based on hierarchical maps is proposed. The method hierarchically characterizes the operating environment of the substation inspection robot, and establishes a hierarchical map including the distribution of obstacles in the substation, the distribution of the passable roads, and the semantics of the primary equipment, so as to realize the setting of the inspection points of the inspection objects on the map. The proposed method has been put into application.

1. Introduction
At present, the substation inspection robots that are put into operation in China mainly adopt the mode of the mobile trolley equipped with the detection device [1]-[2], and conduct inspections on indoor and outdoor high-voltage equipment by means of autonomous or remote control. The detection devices mounted on the substation inspection robot mainly include: visible light camera, infrared thermal imager, sound collection device, etc. The inspection objects mainly include: appearance state of the device, meter reading, local temperature, equipment noise, and the like. This paper mainly focuses on the problem of time-consuming and labor-intensive configuration of existing inspection objects, and proposes a rapid configuration method for inspection objects of substation inspection robots based on hierarchical maps. The method hierarchically characterizes the operating environment of the substation inspection robot, and establishes a hierarchical map including the distribution of obstacles in the substation, the distribution of the passable roads, and the semantics of the primary equipment, so as to realize the setting of the inspection points of the inspection objects on the map. Work, reduce the workload of setting the inspection point near the remote control car to the actual primary equipment.

2. Hierarchical characterization of the operating environment of substation inspection robot
In China, the first-generation substation inspection robot adopts the magnetic navigation method [2], which guides the movement according to the magnetic stripe embedded in the underground. Due to the damage to the substation road facilities, construction difficulties, magnetic stripe loss, etc., it is gradually replaced by autonomous navigation scheme based on laser sensors. Based on the laser sensor-based autonomous navigation scheme, the robot is required to manually guide the robot to travel in the substation. During the process of traveling, the laser sensor installed on the robot body
continuously perceives the obstacle information in the surrounding environment to form an environment for the robot. The global description, that is, the global map; when the robot navigates autonomously, the local map generated by the obstacle information generated by the laser sensor in real time is compared and analyzed with the pre-stored global map to realize the positioning of the robot, the path planning, and the obstacle avoidance. When creating the map, the scheme only uses the obstacle information in the robot running environment, and does not completely model the environment, lacks the road information in the substation, primary equipment information, etc., and cannot set the inspection point remotely through the map. Features. In this paper, the operating environment of the substation inspection robot is hierarchically characterized, and a hierarchical map including the distribution of obstacles in the substation, the distribution of the passable roads, and the semantics of the primary equipment is established, so that the robot can refer to the hierarchical map and walk freely to any equipment.

2.1. Creation of map of obstacle distribution layer in substation
The creation of the obstacle distribution layer map in the substation means that the inspection robot relies on the laser sensor carried by itself, constantly perceives the surrounding environment information during the operation, incrementally creates a map of the surrounding environment, and uses the created map to realize its own position estimate, simultaneous localization and mapping (SLAM). At present, based on the SLAM problem of laser sensors, the commonly used solutions are mainly SLAM algorithm based on extended kalman filter SLAM algorithm based on rao-blackwellized particle filter [3-6]. The algorithm based on extendedkalman filter (EKF) has difficult data association and the calculation problem proportional to the quadratic number of features. The computational complexity increases with the increase of environmental complexity, which is not suitable for substation map creation in a size, complex environment. The SLAM algorithm based on rao-blackwellized particle filter solves the data association problem well, but because of the method, each particle stores its own map and robot positioning result, which also faces the calculation problem proportional to the number of particles. It is still not directly available for map creation in substation environments. In order to realize the map creation of large-scale and complex environment in substation, this paper adopts the improved rao-blackwellized particle filter algorithm described in the literature to minimize the number of particles needed to create accurate maps; In the multi-threaded manner, the matching score process of each particle is processed in parallel to improve the processing speed of the algorithm.

The basic principle of the SLAM algorithm based on rao-blackwellized particle filter is that, when the laser observation value \( z_{1:t} = z_1, \ldots, z_t \) and the odometry value \( u_{1:t-1} = u_1, \ldots, u_{t-1} \) is known, estimate the probability of environment map \( m \) and the trajectory of the robot. The decomposition of the probability \( p(x_{1:t}, m | z_{1:t}, u_{1:t-1}) \) is decomposed into two steps, first, estimate the trajectory of the robot \( x_{1:t} \) through \( z_{1:t} \) and \( u_{1:t-1} \), the probability of which is \( p(x_{1:t} | z_{1:t}, u_{1:t-1}) \); Then, the environment map \( m \) is estimated by the robot running trajectory \( x_{1:t} \) and the laser observation value \( z_{1:t} \), the probability of which is \( p(m | x_{1:t}, z_{1:t}) \). The decomposition process is as shown in equation 1.

\[
p(x_{1:t}, m | z_{1:t}, u_{1:t-1}) = p(m | x_{1:t}, z_{1:t}) \cdot p(x_{1:t} | z_{1:t}, u_{1:t-1})
\]  

(1)

The estimation of the trajectory of the robot can be performed by a particle filter algorithm. The pose of the robot at time \( t \) is estimated by the prior knowledge, and the prior probability density is corrected by the latest observation value to obtain the posterior probability density. The conventional Rao-Blackwellized particle filter algorithm is composed of four steps.

1) Sampling. The motion model of the robot is usually used as the proposed distribution \( \pi \) of the particle sampling, to produces a next-generation particle set \( \{x^{(i)}_t\}_{i=1,2,\ldots,N} \), from the previous generation particle set \( \{x^{(i)}_{t-1}\}_{i=1,2,\ldots,N} \) where \( N \) represents the number of particles.

2) Weight calculation. Calculate the weight of each particle.

3) Resampling. Resampling by particle weight.
4) Map update. For each particle, the maintained map is updated with the particle's trajectory $x_{1:t}^{(i)}$ and the historical observation $z_{1:t}$.

In step 1, the proposed motion distribution using the motion model of the robot as particle sampling is suboptimal. Especially when the observations of the robot are more accurate than the estimates based on the mileage, such as the robot is equipped with a high-precision laser radar, the motion model is still used as the suggested distribution, and a large number of particles will be required to cover the high likelihood region. In this paper, the improved rao-blackwellized particle filter algorithm is used to improve the proposed distribution. The latest observation information is added on the basis of the motion model. The scan matching method is used to construct the multi-modal observation likelihood distribution to make the particle converge. By the most likely observed likelihood modes, the particle diversity is maintained, reducing the number of particles required for estimation.

2.2. Creation of a map of the road distribution layer in a substation

In the early stage of substation construction, the design department completed the planning and design of primary equipment layout, cable orientation and road distribution in the substation; during the construction of the substation, the construction department strictly followed the design drawings. The primary equipment layout, road distribution, etc. of the new substation are generally not very different from the design drawings. The general layout of the substation electrical plane is shown in figure 1.

The figure clearly indicates the installation position of the equipment, the distribution of the road, the direction of the cable, etc. The length, width, corner curvature of the road, etc., the size of the cable trench cover, in figure 1, CH1, CH2, and CH3 represent cable covers of different sizes. After the site survey, the above design information is basically consistent with the relevant information of the actual new substation, and the road distribution layer map can be used as the boundary reference for arranging the inspection object on the map, which itself does not have too high precision, so the design can be adopted. The equipment and facilities layout diagram issued by the department is used as the boundary constraint of the inspection point configuration, that is, the map of the road distribution layer in the substation.

![Fig. 1 Substation electrical general layout example](image)

If the actual scene of the substation and the acquired design drawings are large and large, for example, the old substation after several expansions and reconstructions in the later stage, the archived design drawings are not updated in time. For this situation, the local survey data can be manually drawn and updated according to the site survey data. The matching area.
2.3. Creation of a device semantic layer map

The device semantic layer map, that is, on the basis of the obstacle distribution layer map and the passable road distribution layer map in the substation, increases the layout and attributes of the device once. After the map of the obstacle distribution layer is generated, the primary equipment directly installed on the ground, such as main transformer, capacitor, reactor, etc., the bottom contour of the equipment can be sensed by the laser sensor and displayed in the map in the form of obstacles. The attributes can be marked directly on the map; for breaker, disconnector, earth disconnector, transformers, wave blocks, etc., the body of the device is erected in the air and cannot be directly perceived by the laser sensor, and the device cannot be directly marked on the map. Attributes. Such equipment can be positioned with reference to its support bracket, local operating mechanism box, etc., because the bracket, the local operating mechanism box is mounted on the ground and can be sensed by a laser sensor. Taking a 5011 interval of a 500kV substation as an example, as shown in figure 2, the phase-operated mechanism boxes of the 5011 circuit breaker, 50111 disconnector, 501117 earth disconnector, etc. are represented in the map with their bottom contours, squares or rectangles. The approximate location of the equipment is determined by the location of the local operating mechanism box on the map. In the figure, the yellow, green, and red icons represent the three phases of the equipment, and CB, DS, and GS represent the circuit breaker, the disconnector, and earth disconnector respectively.

Since the primary equipment in the substation has the characteristics of structured and neatly arranged, it is not necessary to manually identify the primary equipment one by one, and the identification of all primary equipments can be quickly completed by copying by interval and by serial copying. As shown in figure 2, after manually performing the positioning and identification of the three-phase A, B, and C devices of the 5011 interval, the device elements and attributes of the identified device can be copied to the 5012 and 5013 intervals, and the scheduling number can be modified in batches. The identification of a string of 500kV devices on the map, and then copying by string, complete the identification of another string of devices in the same wiring mode.

![Fig. 2 Schematic representation of device semantics](image)

3. Conclusion

This paper introduces the hierarchical characterization method of the operating environment of the substation inspection robot, and the map of the obstacle distribution layer in the substation, the map of the road distribution layer in the substation, and the creation method of the semantic map of the primary equipment. The proposed method has been put into application.
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