Research on Indoor Comprehensive Sensor Layout Method Based on Grid Method

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Abstract. With the development of key technologies for environment change perception, accurate perception of user load status becomes possible. Sensing the user's load status can reduce the transformation of the medium-voltage power grid, save the investment cost of the equipment for supporting the construction of the power grid, and improve the investment efficiency of the power grid. In this paper, based on the consideration of the user's indoor scene, space area, flexible device distribution and building structure, etc., with the goal of maximizing the credibility of the indoor perception network, an optimal networked indoor sensor layout model is established. The weight of each sensing grid is calculated based on the sawing mapping, and the layout method with the highest trust is selected as the optimal indoor comprehensive sensor layout scheme. Finally, based on the case of an actual house, the effectiveness and correctness of the proposed model and method in indoor sensor layout are verified.

1. Introduction
In recent years, in the process of power system operation control in various countries in the world, large-scale power outage accidents due to insufficient load perception have increased. Flexible interaction with equipment such as energy storage and energy consumption on the user side improves the overall energy efficiency of the power grid and meets the increasingly diverse service needs of customers, which has become the goal of energy reform. Literature [1] designed a new type of integrated information system for regional environment monitoring and management based on the Internet of Things, and literature [2] designed a distributed Internet of Things power consumption monitoring system for multi-node distribution of power supply network and user load Monitoring, etc. With the continuous development of key technologies of environment perception, the use of sensors to sense user load status has become a hotspot in recent research. User load perception recognition completes the identification of electrical appliances according to their characteristics, including mathematical optimization[3] and pattern recognition[4]-[7]. The deployment of sensors needs to consider the characteristics of the monitoring target. Steffelbae et al. Took the effect of demand uncertainty on potential pressure measurement points as an example and proposed an optimized layout method of sensors that considers the uncertainty of different types and sources[8]; In the performance evaluation of the aging infrastructure, etc., they used the information of static load testing to identify the optimal sensor location and sensor type, and proposed an improved sensor layout algorithm that considers the mutual information between load tests[9], literature[10] An improved pollen pollination algorithm is proposed to optimize the node layout of wireless sensor networks. Reference [11]
improved the original sensor layout method and proposed a sensor layout strategy based on Bayesian network and information.

2. Modeling
The layout of indoor integrated sensors should not only consider factors such as indoor scenes, space area, flexible equipment distribution and building structure, but also consider the number of integrated sensors and layout costs. Using the grid method can comprehensively and accurately perceive the entire monitoring area, which is a method to refine complex problems.

2.1. Indoor perception network modeling
This paper assumes that the maximum sensing radius of the indoor integrated sensor is $r_s$, and the circle with a diameter of $2r_s$ is used as the inscribed quadrilateral, which is the monitoring range of the indoor integrated sensor. The perceptual grids are $M \times N$, the coordinates of each perceptual grid are $(i, j)$, which means the perceptual grid in the $i$-th row and $j$-th column, where $1 \leq i \leq M$ and $1 \leq j \leq N$. $d(i,j) \rightarrow (p,q)$ is the distance from the $(i, j)$ the sensing network to the $(p,q)$ th sensing grid integrated sensor, and the data matrix of the entire indoor environment is $X \in RM \times N$.

![Figure 1. Indoor awareness network.](image)

This paper uses the masking operator $\Gamma(\cdot)$ to represent the layout process of indoor integrated sensors, as shown in formula (1):

$$\Gamma(X \otimes W') = X \otimes W' \otimes Q$$

(1)

Where, $W'$ is the weight matrix of all perceptual grids indoors, and $\otimes$ represents the two matrices are correspondingly multiplied. $Q$ is a perception matrix with $M$ rows and $N$ columns, which is defined as follows:

$$Q(i, j) = \begin{cases} 1 & \text{When the integrated sensor is placed in the (i, j) th perception grid} \\ 0 & \text{Else} \end{cases}$$

(2)

Combine the coordinates of all perceptual networks satisfying $Q(i, j) = 1$ into a comprehensive indoor sensor layout vector:

$$P = \{(i, j) | Q(i, j) = 1\}$$

(3)

Let $k$ denote the number of elements of the $P$ vector, that is, the total number of integrated sensors placed indoors. Considering factors such as indoor scenes, space area, flexible equipment distribution,
and building structure, there are multiple combinations of indoor sensor layouts, and their vectors are shown in formula (4):

$$L = \{L_g | 0 \leq g \leq C^k_{M\times N}, g \in Z\} \quad (4)$$

Where, $L_g$ represents the $g$-th $k$ indoor comprehensive sensor combination scheme, and $g$ is an index of various combination schemes.

$$F(L_g) = P \quad (5)$$

Where, the function of function $F(\cdot)$ is to convert a string of numbers into a series of coordinates in the perception matrix $X$. Formula (5) represents the indoor integrated sensor layout vector $P$ obtained by adopting the $g$-th combination scheme $L_g$.

Indoor comprehensive sensor coverage is defined as $SCO$:

$$SCO = \frac{COS}{AS} \quad (6)$$

Where, $AS$ represents the indoor space area, and $COS$ represents the effective sensing area of all integrated sensors.

$$COS = \sum_{i=1}^{M} \sum_{j=1}^{N} CO(i,j) \times S(i,j) \quad (7)$$

The denser the indoor comprehensive sensors are distributed, the more the superimposed area will cause the lower perceptual coverage of the entire network. $SCO$ reflects the intensity of indoor comprehensive sensor layout. The area-aware coverage prevents the sensor layout from being concentrated at one point, because the concentration at a point makes the area-aware coverage smaller.

### 3. Optimal model of indoor comprehensive sensor layout

The credibility of the indoor integrated sensor monitoring network is the sum of the perceptual reliability under a certain perceptual coverage ($SCO$), which is expressed by $TR(\cdot)$. The higher the $TR(\cdot)$, the higher the reliability of the collected data and the better the performance of the monitoring network.

In consideration of indoor scenes, space area, flexible equipment distribution, building structure and other factors, the layout of indoor comprehensive sensors is actually to obtain the best layout plan through the following optimization methods.

$$P^* = \arg \max_{P} TR\left(\Gamma\left(X \otimes W'\right)\right) \quad (8)$$

$$s.t. k = M \times N$$

Where, $P^*$ represents the optimal indoor comprehensive sensor layout plan finally obtained. In the actual layout, it is very important to ensure the effective collection of data from the indoor monitoring network, and there will be situations where there is a minimum requirement for the sensing capabilities of the sensor grid. Therefore, considering that the minimum sensor reliability $R_{min}$ and the data loss probability threshold of the indoor sensor grid are a dual concept, the optimized model of the indoor comprehensive sensor layout can be expressed as:

$$P^* = \arg \max_{P} TR\left(\Gamma\left(X \otimes W'\right)\right) \quad (9)$$

$$s.t. R(i,j) \geq R_{min}$$

### 4. Case study

In order to verify the validity of the indoor comprehensive sensor layout scheme proposed in this paper, considering the indoor scene, space area, flexible equipment distribution and building structure, etc., the perception of indoor environmental data is considered. It performs verification analysis. Compared with different matrix weights, the credibility of sensor networks in various indoor integrated sensor layout combinations is compared. This article assumes that the sensing grid is a
regular square, and assumes that the indoor sensors have the same perceptual accuracy, that is, the $\alpha$ and $\beta$ of each integrated sensor are the same. The specific parameters are shown in Table 1.

| Parameter Description | Value          |
|-----------------------|----------------|
| Indoor area $S$       | 100m$^2$       |
| Minimum sensing radius $r_s$ | 10m     |
| Regulatory factor $\alpha$ | 1           |
| Device parameters $\beta$ | 1           |

In this paper, a layout method with the highest degree of trust is selected as the optimal indoor comprehensive sensor layout scheme. The weight of the sensor grid formed by the sensor area is related to the indoor space area, the density of flexible equipment distribution, and the ease of building construction. The weight of all the grids in the sensor area constitute the weight matrix of the indoor comprehensive sensor network. In order to compare the different sensor credibility obtained under the weight matrix of different sensor networks, this paper randomly sets the estimated parameters of the weight matrix $W_1$ and $W_2$ as shown in Table 2 and Table 3, respectively.

In order to further analyze the effect of grid weights on the data collection effect, this paper compares the best and worst cases of the two weights together. • indicates the location of the sensor layout coordinates with the highest reliability, and $\triangle$ indicates the lowest reliability. The coordinate position of the sensor layout of the sensor is shown in Figure 2. In Figure 2 (a), the coordinate position of the sensor layout with the highest reliability is $\{(1, 2), (2, 1), (3, 1), (3, 2)\}$, the coordinate position of the least reliable sensor layout is: $\{(1, 1), (1, 2), (2, 1), (3, 1), (3, 2)\}$, in Figure 2 (b), the coordinate position of the most reliable sensor layout is: $\{(1, 2), (1, 3), (2, 1), (2, 2), (2, 3)\}$, the coordinate position of the least reliable sensor layout is: $\{(1, 1), (2, 1), (3, 1), (3, 2), (3, 3)\}$.

| Parameter Description | Value                      |
|-----------------------|----------------------------|
| Size of indoor space area $PL_{ij}(m^2)$ | $\{11, 2, 9; 0.5, 1, 9; 0.5, 3, 8\}$ |
| Distribution density of flexible equipment $DN_{ij}$ | $\{2, 1, 0.5; 0.3, 3, 1; 0.1, 4, 1\}$ |
| Ease of construction $TN_{ij}$ | $\{0.1, 0.3, 0.8; 0.9, 0.25, 0.1; 0.4, 0.6, 0.7\}$ |

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![Figure 2](image-url)
It can be seen from Figure 3 that the sensor layout with the lowest reliability is basically arranged on the edge of the sensing area, and is arranged on a grid with a lower weight. The layout methods of sensors with higher reliability are basically in the grid with higher weight, and most of the sensors are arranged in the center of the sensing area.

5. Conclusion
In this paper, the grid method is used to study the optimal indoor comprehensive sensor layout plan to ensure full coverage of data collection, so as to achieve panoramic perception of indoor environmental data. Select the actual data of a house for case analysis, consider factors such as the user's indoor scene, space area, flexible equipment distribution, building structure, etc., and build an indoor comprehensive sensor perception network model. Calculate the weight of each perception grid through zigzag mapping, and aim at the maximum credibility of the perception network. In the perception network with different weights, from the layout combination of 126 indoor integrated sensors, the maximum coverage and perception The most reliable indoor comprehensive sensor layout method. It is proved that the indoor integrated sensor perception network model constructed in this paper optimizes the layout of indoor integrated sensors, it can completely cover indoor scenes, fully and accurately perceive indoor environmental data, and then analyze user load status to improve power grid investment efficiency.

Acknowledgments
Supported by Science and Technology Project of State Grid "Research and application of key technologies of load sensing, measurement and control for low voltage users" (SGHEDK00DYJS2000044).

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