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ORIGINAL ARTICLE

Engineering operation management technology based on network automation configuration visualization

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Abstract This study designed a visual management software for WIA-PA network. Firstly, based on the characteristics of WIA-PA network, the main functions and design requirements of visual management software are analyzed. Then the decoupling between modules and the network topology layout algorithm are designed. The traditional register mode is improved to form index mode, and the software development is realized with builder mode. The model can effectively decouple from packet analysis, data storage and application, and has good hardware platform compatibility. Based on the improved tension repulsion model, a heuristic network topology layout algorithm based on node attributes is designed. When the number of devices is 21, 41, 81 and 161, the execution time of the algorithm is 31MS, 62 ms, 109 ms and 250 ms respectively. The algorithm has the best performance in solving the network layout with less than 100 devices, and the network topology layout is clearer, which provides an important support for the hardware platform compatibility of visual management software.

Keywords Network automation · Configuration · Visualization · Project operation · Management system

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1 Introduction

At present, WIA-PA is the standard of wireless communication system structure in China. WIA-PA network takes data as the center, which can realize network automation configuration visualization, and is widely used in the measurement, monitoring and control of industrial processes. The visualization management software combined with WIA-PA network can realize the collection, storage, management and visual display of project operation data, and provide strong technical support for users (Tsyrkov et al. 2018).At present, there is no visual management software for WIA-PA network, which mainly realizes the visualization of WIA-PA network information through wireless sensor network visualization. The team of Yuri Das Neves valad @ o clarified the operation mode and evolution process of industrial wireless sensor network, and summarized some equipment currently applied in WIA-PA network and some applications related to this technology (Yuri das Neves Valadão et al. 2018). Wei m and other scholars proposed a wireless sensor network security testing method based on security level, and built a wireless sensor network security test platform based on wia-pa. The test results show that the platform has certain practicability (Wei and Kim 2016). Wang Q and other scholars discussed the key technologies of the four most popular industrial wireless sensor network standards ZigBee, WirelessHART, isa100.11a and WIA-PA, compared their detailed design and protocol architecture, and inspected the applicability of these standards to meet industrial requirements (Wang and Jiang 2016). Jin X's team proposed a real-time aggregation scheduling method for WIA-PA networks. Simulation results show that the earliest deadline first real-time scheduling algorithm is the preferred method for WIA-PA network (Jin et al. 2018).

Based on IEEE 802.15.4, Li Z and other scholars analyzed the three standards of industrial wireless network and their development trend. Matlab is used to verify the practicability of the wireless system from the control performance and power consumption of the wireless network (Li et al. 2017). Wang J's team discussed the application potential of blockchain technology in engineering construction management, and believed that the application of blockchain could improve the existing contract management, supply chain management, equipment leasing and other processes (Wang et al. 2017). In view of the situation that hierarchical data management cannot be realized in the marine collective engineering management system, Zhao x adopts the big data BS architecture to optimize the overall framework of the collective engineering management system, and the management efficiency of the system is 34.5% higher than that of the traditional engineering management system (Zhao 2018). Nicolson J and other scholars analyzed the operation strategy of oil well engineering management system, focusing on the key of risk management and appropriate front-end loading of engineering tasks. Work with the girl Macintosh team to ensure that the data of the management system is accessible to users of eikos software (Nicolson et al. 2018). Liu D and other scholars evaluated the power engineering cost management system based on the fuzzy comprehensive evaluation model, established a complete set of power engineering cost control system, and verified the feasibility of the scheme by taking an electric power construction enterprise as an example (Liu et al. 2018). Miranda C and other scholars have proposed a software defined security framework, which combines intrusion prevention with collaborative anomaly detection system. This model has less security and has the ability to reduce false alarm (Miranda et al. 2020). Huang R's team proposed a topology optimization model for wireless sensor networks based on complex network theory and network physical system. Theoretical analysis and experimental results show that the proposed topology optimization model has both small world effect and scale-free characteristics, which can improve the robustness of wireless sensor networks and structural invulnerability (Huang et al. 2017). Schulz Zander J and other scholars proposed and evaluated a new WiFi architecture opensdwn based on SDN and nfv methods, which can be used to outsource the control of home network to participatory interface or Internet service providers (Schulz-Zander et al. 2017). Datsika e.g. and other scholars have designed a multi hop wireless network resource allocation method based on multi hop coding, and proposed a joint quality enhancement and power control problem based on utility function, which not only reflects the advantages of video quality, but also reflects the cost of transmission power (Datsika et al. 2016). Laghari s team uses agent-based modeling as part of the cognitive agent-based computing (CABC) framework to model complex communication network problems. The experimental results show that the method can effectively model the complex problems in the field of Internet of things, and the specific problems of carbon footprint management can be solved by using multi-agent system method (Laghari and Niazi 2016). In order to solve the problem that UC of images collected by wireless sensor networks can be encoded in a jumbled manner, Kim s and other scholars proposed a new WVSN lifetime maximization strategy, and the effectiveness of the strategy was verified by numerical calculation (Kim et al. 2016).

Based on the above research results, there are some problems in the decoupling between modules and data visualization in the current visual management software, and the development cycle of the visualization management software based on three-dimensional space is long, and is limited to the application of industry domain map library. In order to design a multi industry available management software to meet the practical needs, a visual management software based on WIA-PA network topology algorithm is designed. Firstly, the overall structure and main function modules of the visual management software are introduced; then the core technology design of the visual management software is described, including WIA-PA network topology layout algorithm and decoupling design method; finally, the function and performance of the visual management software are tested.

2 WIA-PA network visualization management platform

2.1 Visualization software of whole structure

The main modules of the visual management software architecture are: implementation memory module, database module, display module, communication module and management module. The management module includes information configuration module and data management module. The communication module includes communication interface module and data analysis module. The display module includes table component module, graph component module, network topology component module, tree list component module and other UI modules. The communication module is responsible for the collector's task; the real-time memory module and database module play the role of registration warehouse; the display module is equivalent to the user; the management module mainly provides the representation information including behavior index or location index.

Figure 1 is the working framework of the visual management software. Its working principle is: the communication module collects the data information in the WIA-PA network, and transmits the information to the real-time memory module and database module. The real-time memory module and database module complete the data storage and update, and the data information can be displayed by the display module. The communication interface module uses multithreading mode to realize concurrent communication with multiple clients. The workflow of data analysis module is to obtain data package, parse data package and re package data package. The data stored in the real-time memory module are: device serial number, manufacturer identification, device short address and 64 bit global unique system. Considering the stability and running speed, MySQL open source software is selected as the underlying database of visual management software (Kidwai et al. 2016).

2.2 Function analysis of visualization software

The visual management software needs to have the functions of data storage, management, analysis and query. As the WIA-PA network requires data centric, there are some specific requirements for the different functional modules shown in Fig. 1. WIA-PA network perception information is not uniform, which requires the analysis function in the communication module to have static expansion ability; the storage logic of real-time memory module and database module has static variability; the table and curve visualization function of display module has static expansion ability; the management module can instantiate the ability to describe file management (Al Mamun et al. 2016). Due to the huge amount of data sensed by sensors, the database module needs to design correct table building rules and storage rules (Elivelton, et al. 2019).

Figure 2 is the data sequence diagram of visualization software function flow. The user selects and opens the communication endpoint through the display module. The communication module calls the configuration file in the management module to receive and parse the data packets from the data source device. The realization process of data storage function of visualization software is as follows: database module and trial memory module call configuration file information to management module, obtain and analyze data information from communication module, and finally realize data storage according to specified storage rules. The functions of the management module mainly include static expansion and data management. The implementation process of static expansion is: the user changes the configuration file of the management module through the display module. After receiving the updated information, the management module calls the configuration files of the communication module, the real-time memory module and the database module, and reconfigures the file information according to the updated information conveyed by the user. The work-flow of database data management is: the user sends management operation to the management module through the display module, the management module calls the operation function of the database module, and the database module realizes the deletion of database data or the establishment of new tables according to the management operation information conveyed by the management module.

Figure 3 shows the running process of data query function of visual management software. The user sends the real-time data query command written by the software to the real-time memory module through the display module to query the real-time data within one week, and issue historical data query command to database module to query historical data. The real-time memory module and database module in the software return the data to be queried according to the information input to the display module, and display the data on the display module to complete the data query. The realization process of data visualization function is: the user selects the visualization function in the display module, and the management module reads the corresponding business logic and

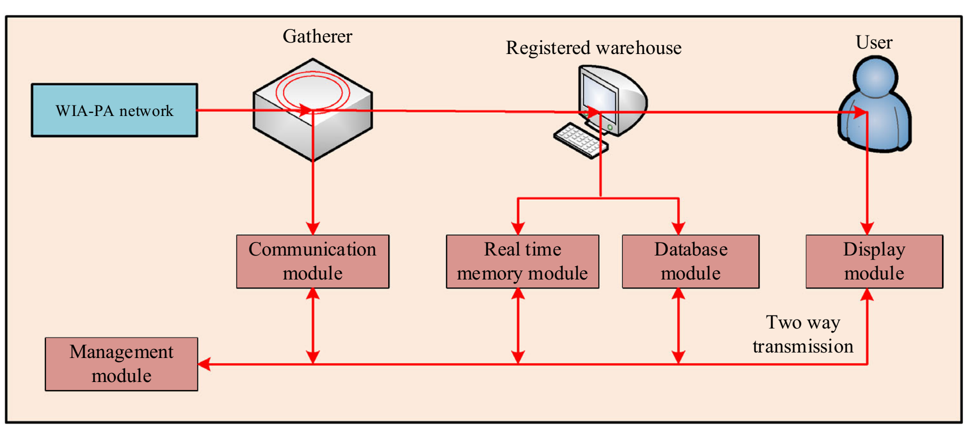


Fig. 1 Visual management software architecture

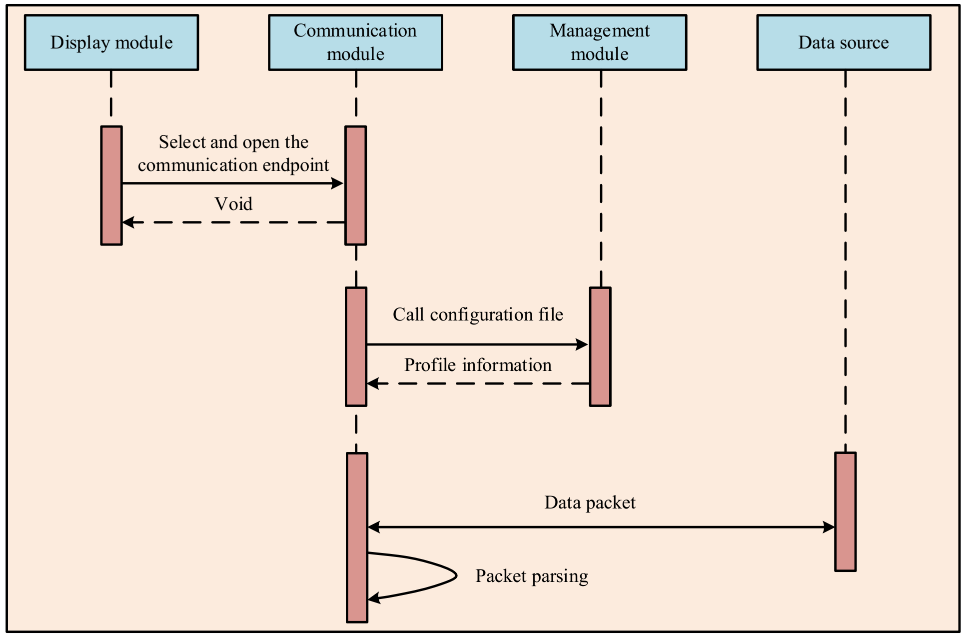


Fig. 2 Data sequence diagram of software function flow

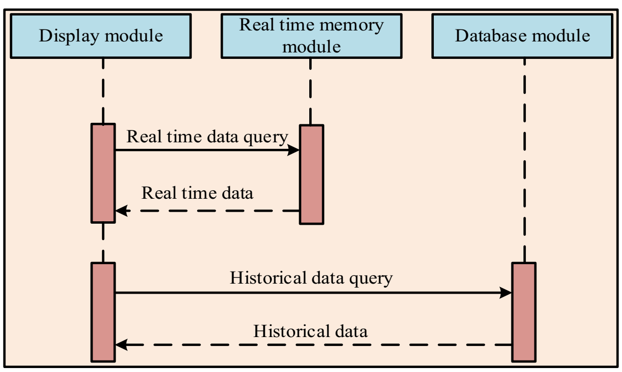


Fig. 3 Operation flow chart of data query function

instantiation description file. The display module sends the command of querying parameters to the real-time memory module or database module according to the user input requirements, and finally receives the parameter information and displays it on the screen.

2.3 Decoupling design of visual management software

Coupling refers to the measurement of the correlation degree between different modules in the software. The coupling in the visual management software includes data package analysis coupling, data storage coupling and data application coupling. The existence of these three kinds of mutual coupling may lead to tight coupling between software and hardware platform, affect the compatibility of hardware platform, and in serious cases, may lead to software failure to run (Sheng et al. 2017). Based on this, this paper studies the decoupling design of the visual management software, and designs the object access mode between modules of the visual management software. The decoupling process of data package is divided into three parts: packet identification, field interception and field data analysis. The decoupling process of data storage includes two parts: selecting data structure and storing data; the decoupling process of data application includes application function instantiation and data acquisition.

The core idea of object access between modules is to use data retrieval method to improve the register mode. The main contents are: adding collector, location index, behavior index and data element roles; improving user roles; merging registrant and registry roles. The third party is introduced to classify the generation, storage and application of objects, which effectively reduces the coupling between modules and achieves the purpose of decoupling(Gorka et al. (2018)). Name the schema index mode.

Figure 4 is the index pattern sequence diagram of the study, which shows the process of generating, storing and accessing the sharing meta objects, as well as the cooperation among the participants. In the index mode, the process for users to realize the index is as follows: the collector obtains the behavior index, parses the data packet according to the index content, and forms the sharing object. If it is detected that the sharing element object is not in the registration warehouse, it will be put into the registration warehouse; if the sharing object is in the registration warehouse, the sharing element object in the registration warehouse will be updated. Finally, the user obtains the location index and key, and realizes the query

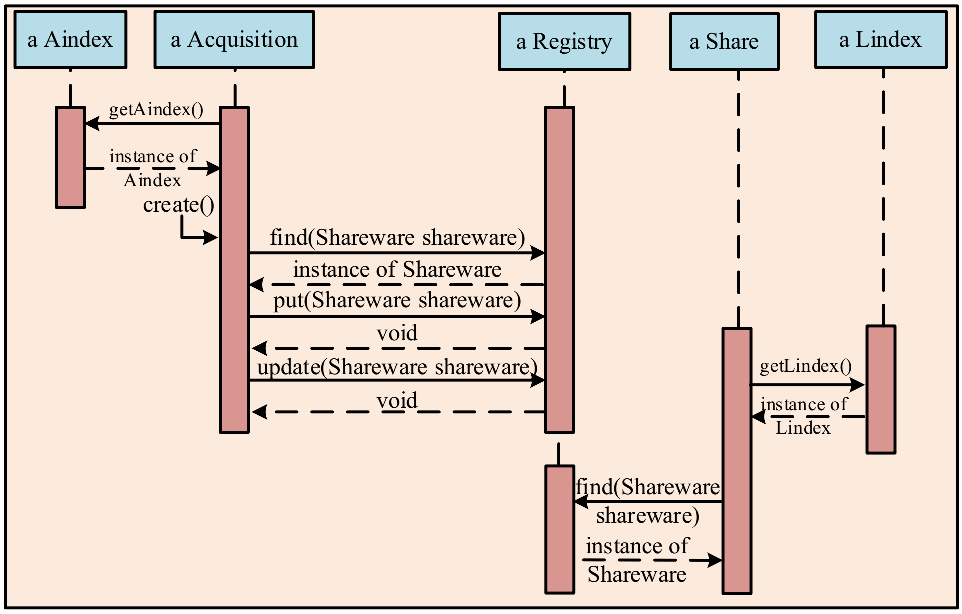


Fig. 4 Index pattern sequence diagram

of the sharing meta object to complete the application function.

2.4 Design of WIA-PA network topology layout algorithm

The core of the visual management software is WIA-PA network, which has two topologies: hybrid topology and star topology (Akbar et al. 2020). The two networks are shown in Fig. 4.

Figure 5a is the network diagram of WIA-PA network star topology structure, which is composed of PC, gateway devices and field devices. Gateway devices are the cluster heads of all field devices. Figure 5b is a network diagram of WIA-PA hybrid topology, which includes PC, gateway device, routing device and field device. The first layer is the gateway equipment and routing equipment of mesh structure, and the second layer is the star structure composed of routing equipment and field equipment. In this architecture, there is and only one path for field devices and routing devices (Huhtamäki et al. 2015).

The topology used in WIA-PA network is based on repulsion tension model. This paper studies the improvement of repulsion tension model to form a heuristic local algorithm based on node attributes. The topological structure graph of WIA-PA network is mapped to any undirected graph $G(V,E)$, where V is the set $\{v_1, v_2, \ldots, v_n\}$ of n vertices and E is the set $\{e_1, e_2, \ldots, e_m\}$ of m edges. The vertex is the node and the connection is the edge. The process of vertex clustering pre layout algorithm is as follows:

First, input the cluster region set formula

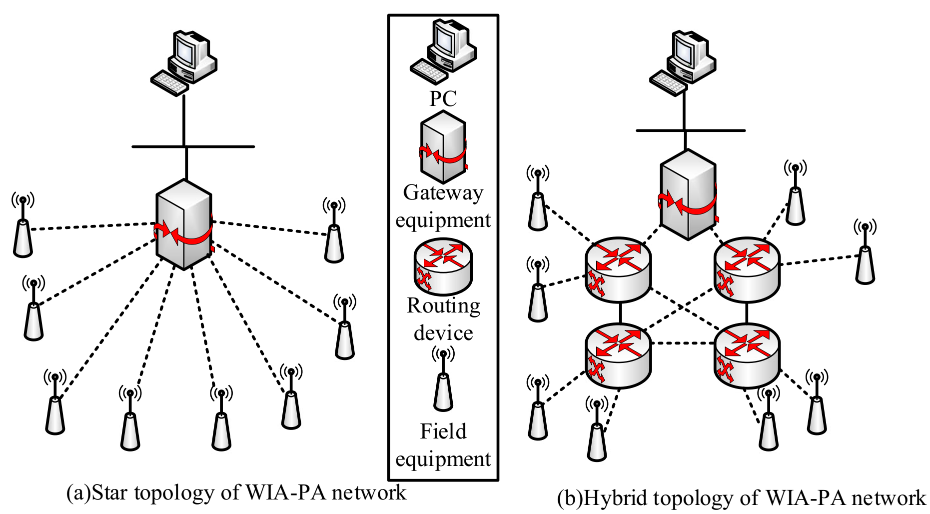


Fig. 5 WIA-PA network topology

$$\begin{cases} Z = \{Z_i | Z_i = R_i \cup T_i \cup W_i, 0 \le i \le n\} \\ B_2 = \{T_i - Q_i | 0 \le i \le n\} \\ C_1 = \{W_i | 0 \le i \le n\} \\ C_2 = \{K_{ij} | 0 \le i \le n, 0 \le j \le m\} \end{cases} \quad (1)$$

Formula (1) is the definition of cluster region set Z,B_2,C_1,C_2. Z area is the logical area formed by router device node and field device node. B_2 area is the logical area formed by gateway device node and router device node whose destination gateway device address is the gateway device address. C_1 area represents the logical area formed by the gateway device node and the field device node whose destination gateway device address is the gateway device address. The C_2 area is the logical area formed by the field device node with the routing device receiving the order and the destination routing device address being the routing device address.

T_i in formula (1) is the top point set of routing device class with destination address R_i. The vertex set of field device class with only one path to R_i is W_i, and the vertex set of routing device class with only one path to R_i is Q_i, and the vertex set of field device class with one path to T_{ij} is Q_i. The number of elements in K_{ij} set is n_{k_i}.

Let $i = n_R$, when $i \le n_R$. R_i,O is defined as the vertex set and center point set of network device class. O_i is the i point in the set O.The coordinate of point R_i is (x_{R_i}, y_{R_i}), the coordinate of point O_i is (x_{O_i}, y_{O_i}), the coordinates of PC top point are (x_{PC}, y_{PC}).

$$\begin{cases} x_{R_i} = \dfrac{L}{n_R + 1}(i+1) \\ y_{R_i} = y_{PC} + d_0 \end{cases} \quad (2)$$

$$\begin{cases} x_{O_i} = x_{R_i} \\ y_{O_i} = y_{R_i} + d_1 \end{cases} \quad (3)$$

In formula (2), L represents the horizontal distance of the drawing. d_0 is the vertical distance between gateway device class vertex and PC set-top point, d_1 is the vertical distance between gateway device class vertex and regional center point.

$j = n_{T_i}$ can be obtained from formula (2) and (3). When $j \le n_{T_i}$, there is a geometric relationship as follows: T_i with O_i as the center of the circle makes a uniform circular distribution, Q_i is located above the ring, and the center is symmetric. From this we can get: $j = n_{W_i} + n_{K_{ij}}$. When $j \le n_{W_i} + n_{K_{ij}}$, there is a geometric relationship as follows: W_i and K_{ij} are uniformly distributed in a circular shape with the points R_i and T_{ij} as the centers respectively.

The vertex of K_{ij} routing equipment is (x_a, y_a). In order to avoid the wrong balance calculation after the node holds the force attribute, the coordinates of the *num* field device class vertex are set as follows(Chahuara et al. 2012):

$$\begin{cases} x_{num} = x_a + d_2 * \cos\left(\dfrac{90*(n_{T_i}-2)}{n_{T_i}} - \dfrac{180}{n_{K_{ij}}} + num * \dfrac{360}{n_{K_{ij}}}\right) \\ y_{num} = y_a + d_2 * \cos\left(\dfrac{90*(n_{T_i}-2)}{n_{T_i}} - \dfrac{180}{n_{K_{ij}}} + num * \dfrac{360}{n_{K_{ij}}}\right) \end{cases} \quad (4)$$

The effect of vertex force is adjusted. It is assumed that there is no force attribute at the vertex of network equipment class, and the concept of central repulsion force is introduced. The regional center point O_i has the repulsion property as shown in formula (5), which can produce repulsion force on the vertex in K_{ij}.

$$F_R = \frac{g * m_1 * m_2}{r^2} \quad (5)$$

Based on the pre layout algorithm and the improved tension repulsion model, a heuristic network topology layout algorithm based on node attributes can be formed. The algorithm process is as follows: initialize variables and vertex holding power, set vertex clustering pre layout, let $i = n_Z$, then $j = n_{Z_i}$. If all elements in F_{ij} are 0, then all elements in F_{ij} are not all 0, and the moving distance of each point in N_{ij} region along f_{ijk} direction is d.

The performance index of the proposed algorithm is time complexity, the calculation formula is as follows:

$$T(N) = O(N) \quad (6)$$

Formula (6) is the calculation formula of time complexity $T(N)$. The time complexity of the heuristic network topology layout algorithm is related to the number of elements in K_{ij} with the largest number of elements. The variable is defined as *Max*, and the total number of WIA-PA network device nodes is N.

In WIA-PA network, when the number of field device nodes with one path and routing device node is evenly distributed according to the number of routing nodes, the total number of gateway device nodes, PC nodes and field device nodes with two or more paths with routing device nodes is i, and the number of routing device nodes is j.

$$Max = \frac{N - i - j}{j} \quad (7)$$

$$T(N) = O\left(\left(\frac{N-i-j}{j}\right)^2\right) \le O\left(\left(\frac{N-j}{j}\right)^2\right) \quad (8)$$

According to formula (7) and (8), when *Max* is equal to 0, the time complexity of the topology layout algorithm is as follows:

$$T(N) = O(N) \quad (9)$$

The time complexity calculation formula of topology layout algorithm based on improved repulsion tension model is as follows:

$$T(N) = O(N^2) \tag{10}$$

3 Performance test of WIA-PA network visualization management platform

3.1 Simulation comparison of algorithm effect

In order to verify the effectiveness of the local algorithm based on the improved repulsion tension model, the topology layout of 35 node and 40 node WIA-PA network is simulated, and the simulation results are shown in Fig. 5.

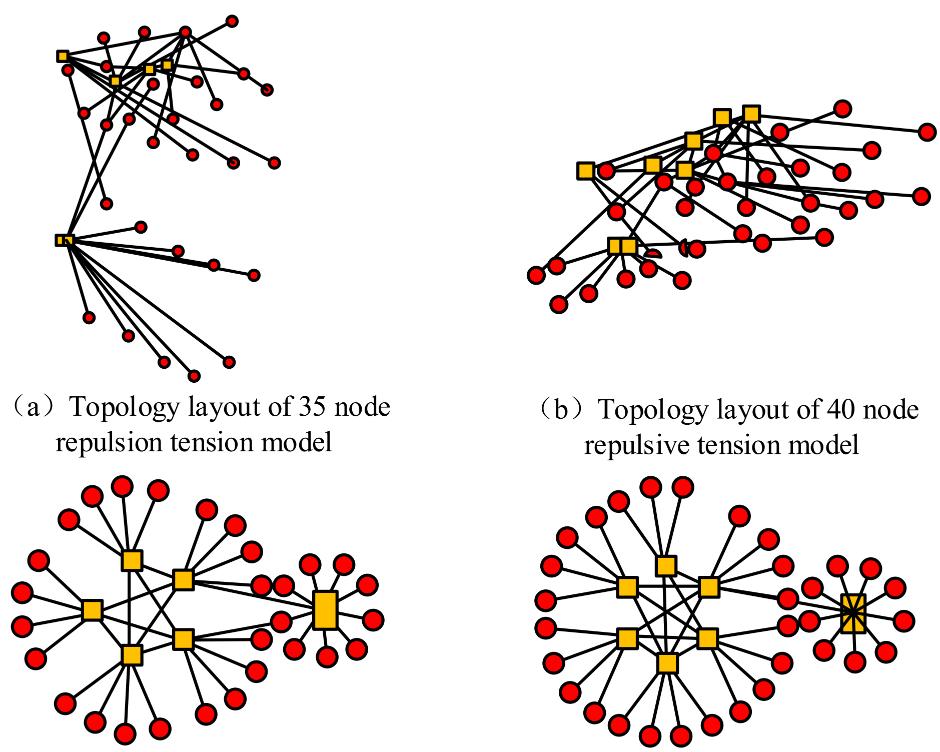
Figure 6a and b are the layout results of the improved topology layout algorithm under 35 nodes and 40 nodes. Figure 6c and d are the topological graph layout results of the topology layout algorithm based on node attributes under 35 nodes and 40 nodes. It can be seen from the figure that both algorithms support star topology and hybrid topology in WIA-PA network. Compared with the topology of tension repulsion model under 35 nodes, the topology layout under 40 nodes is more chaotic. The topological structure in Fig. 6c and d is more clear, which can reflect the topology of the network intuitively even under 40 nodes. This shows that the performance of the topology layout algorithm is better.

Figure 7 shows the simulation results of the time complexity of the two algorithms. The blue dotted line in Fig. 7 is the simulation result of the original heuristic network topology layout algorithm, and its time complexity is much higher than that of the improved algorithm. When *Max* is equal to 0, the time complexity of the improved topology layout algorithm is relatively small. When *Max* is not equal to 0, because *Max* is less than *N*, the time complexity of the improved algorithm is still less than that of the previous algorithm. The simulation results show that the performance of the topology layout algorithm is improved obviously.

3.2 System performance test environment and method

The test tools mainly include routing equipment, field equipment and gateway equipment. The working parameters of main chip and core chip are shown in Table 1. The software testing tools include Wireshark, Navicat for MySQL and smartrf protocol packet sniffer, which are used to analyze network packets, view database information and analyze IEEE802.15.4 standard data packets respectively.

The function test system includes 1 gateway device, 2 routing equipment, 4 field devices, 1 packet grabber and 1 PC. The performance test system has four kinds of analog



(a) Topology layout of 35 node repulsion tension model

(b) Topology layout of 40 node repulsive tension model

(c) 35 node topology layout of the algorithm

(d) 40 node topology layout of the algorithm

Fig. 6 Topology layout of different algorithms under 40 nodes and 30 nodes

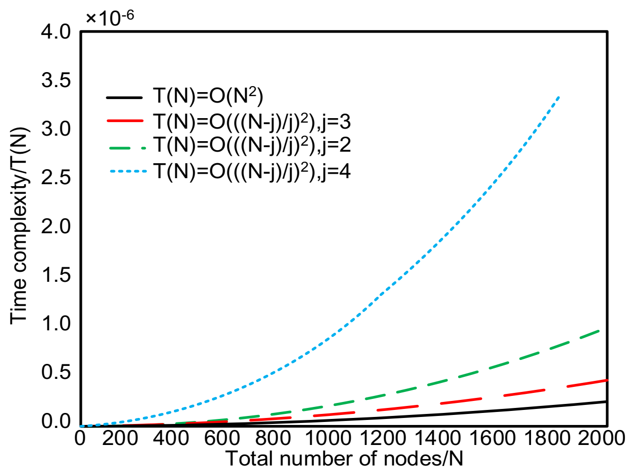


Fig. 7 Simulation chart of time complexity comparison

network forms, and the number of routing equipment and field equipment in different forms is different: 4, 16; 8, 32; 16, 64; 32, 128. The specific operation of the performance test is as follows: call the inter group module of network topology graph to read four configuration files in the form of simulated network respectively, and test the execution time and layout effect of the network topology layout algorithm based on node attributes.

3.3 Function test results

The equipment in WIA-PA network is connected to the network, and the field equipment 0 × 0102 is selected to send periodic data 00210904210602010001 01 to verify the data acquisition and storage functions. The short address of the data string is 0102 and the temperature is 33.000. The cycle data displayed by Navicat for MySQL and the storage data displayed in the visualization management software are consistent with the input data, which verifies the effectiveness of the data acquisition and storage function of the visual management software.

Call the graph group module to query the real-time data and historical data of 0 × 0102, and the results are shown in Fig. 8. The result of useful data obtained in Fig. 8a and b is 33.000, which is consistent with that of data acquisition and storage module, which shows the correctness of data query function of visual management software. Both smartrf protocol packet sniffer and Wireshark can be used to query real-time data and historical data.

The real-time data of 0 × 0101 and 0 × 0102 are monitored by using the graph component module of curve group, and the results are shown in Fig. 9. As can be seen from Fig. 9, the visual management software has multi-sensor sensing data and can monitor multiple data at the same time. This method can also be used to test the table component module.

The visual management software conducts visual test on multiple sensors of the same device, and the results are shown in Fig. 10a. It can be seen from the figure that the visualization management software can simultaneously carry out visual test on three temperature data, and the data display is clear and the discrimination is high. The results of selecting one or more curves by operation with visual management software are shown in Fig. 10b. It can be seen from the figure that the visualization management software has the function of multi perception data visualization for the same device.

3.4 Performance test results

The algorithm execution time of the last device coordinate is selected as the performance index. The execution time of the network topology layout algorithm is the time from the beginning of calculation to the completion of the calculation of all equipment coordinates. The test results show that when the number of devices is 21, 41, 81 and 161, the execution time of the algorithm is 31MS, 62 ms, 109 ms and 250 ms respectively. With the increase of the number of devices, the network size of WIA-PA network gradually increases, and the execution time of the algorithm also increases.

Figure 11a and b show the layout effect of WIA-PA network topology with 21 and 41 devices respectively. It can be seen from the graph that the heuristic network topology layout algorithm based on node attributes can effectively display the network structure of the topology graph. With the increase of the number of devices, the network structure of WIA-PA network becomes more and more complex, and the network topology layout of 41 devices is more complex. The performance of the proposed algorithm is the best when the number of devices is less than 100. With the increase of the number of network

Table1 Hardware testing tools

Equipment name	Core components	Working parameters
Routing equipment	STM32l152RB main control	Frequency: 32 MHz
Field equipment	chip, UZ / CY2420 RF chip	Voltage: 1.65 V ~ 3.6 V
Gateway device	YC2240-F-V5.1 core board, ARM920T core chip S3C2240A	Frequency: 400 MHz

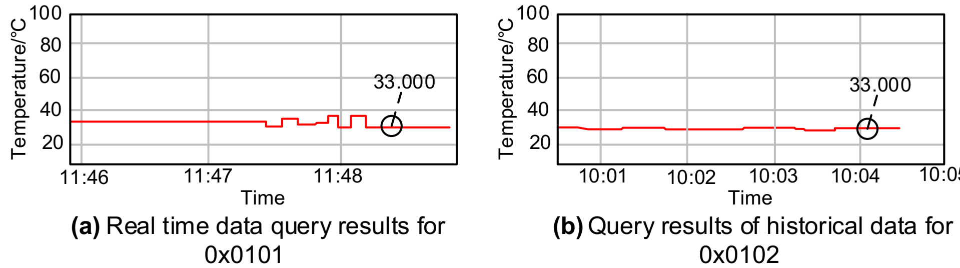


Fig.8 Test results of data query function

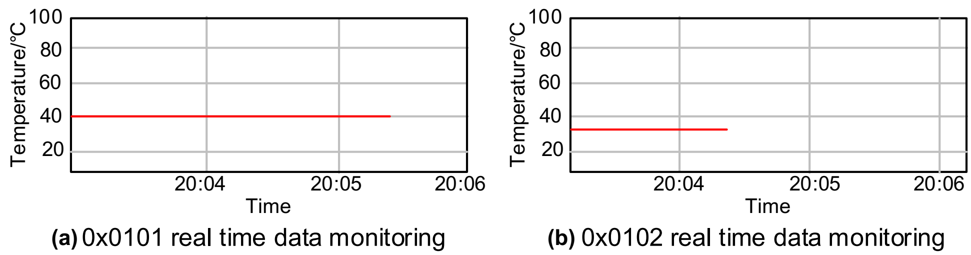


Fig. 9 Multi sensor sensing data simultaneous monitoring function test

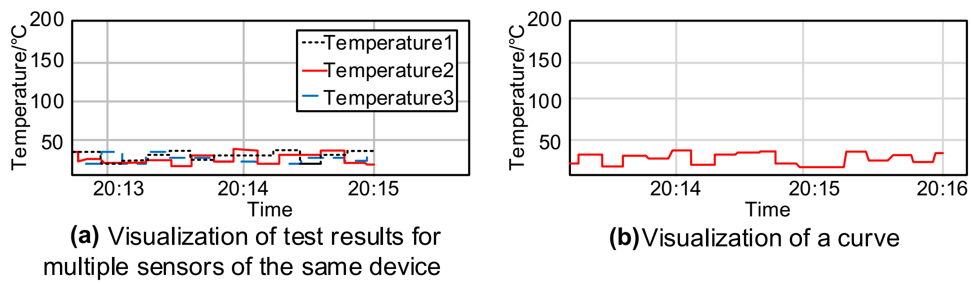


Fig. 10 Multi sensor data visualization function test of the same equipment

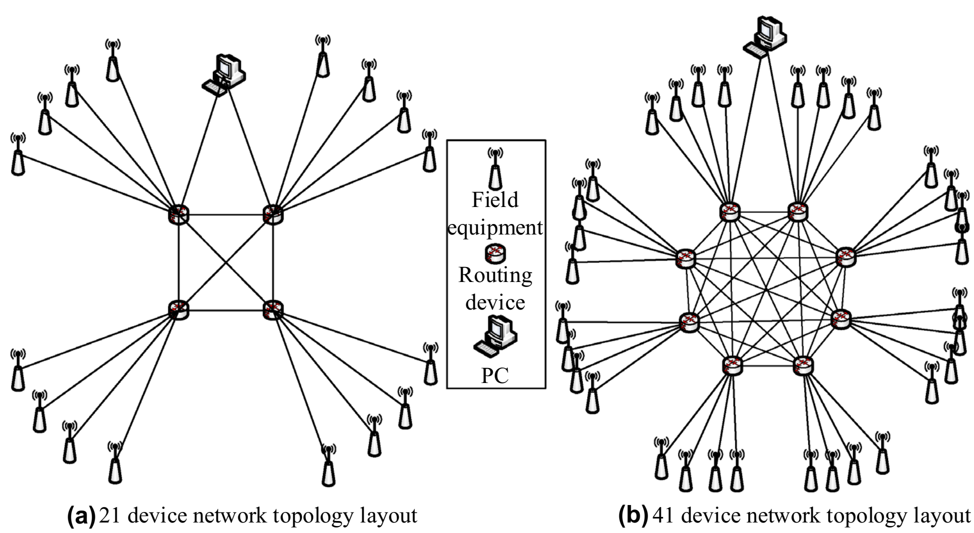


Fig. 11 Layout of network topology with different number of devices

devices, the time complexity of network topology layout will increase exponentially. In the network layout, every node added, the algorithm needs to add the point that produces the greatest benefit to the optimal solution set, and the time consumed in this process is the main source of the increase in the time complexity of the algorithm. In order to measure the time complexity of network topology placement algorithm, the time complexity of simultaneous interpreting algorithm is introduced by introducing parameter K. The k values of the original heuristic algorithm are 1530 and 2415 for 21 and 41 devices respectively, and 318 and 409 for WIA-PA algorithm respectively. The time complexity of WIA-PA network topology layout algorithm is lower than that of heuristic network topology layout algorithm, which can effectively shorten the layout time in practical application.

4 Conclusion

Based on the characteristics of WIA-PA network, the project operation management visualization software based on WIA-PA network is studied and designed. The visual management software mainly includes display module, management module, real-time memory module and communication module. The software takes data as the center, and can realize data collection, storage, management, query and visualization. Based on the WIA-PA network topology structure, the tension repulsion model is improved by using the heuristic topology layout algorithm. The central repulsion force is introduced and the force attribute of network equipment class vertex is ignored. Finally, a network topology layout algorithm which can directly reflect the WIA-PA network structure is designed. The algorithm has low time complexity and can effectively solve the display problem of WIA-PA network topology. Due to the non-uniformity of WIA-PA network sensing information and the diversity of multiple sensor attributes, the research puts forward specific requirements and implementation methods for specific modules of visual management software. The results of system function and performance test show that the visual management system can effectively realize the functions of data acquisition, storage, management and visual display. The performance test results show that the implementation time of the visual management software is reasonable, and can display the network topology with clear structure within 100 devices. When the number of sensors is 21, the time complexity of the algorithm before and after the improvement is 1530 and 318; when the number of sensors is 41, the time complexity of the algorithm before and after the improvement is 2415 and 409, and the time complexity of the improved network layout algorithm is significantly reduced.

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