Hindawi
Advances in Multimedia
Volume 2022, Article ID 7012779, 8 pages
https://doi.org/10.1155/2022/7012779

Research Article

Improved Routing Protocol Based on Multiobjective Optimization in Industrial Robot Networks

You Wu Liu,[1,2] **Syazwina Binti Alias**,[2] **Ming-yue Liu**,[2] **and Bian-bian Jiao**[2,3]

[1]*School of Economics and Management, Sanming University, Sanming 365004, China*
[2]*Faculty of Engineering, Built Environment and Information Technology, SEGI University, Kota Damansara 47810, Petaling Jaya, Malaysia*
[3]*School of Information and Electrical Engineering, Shandong Jiaotong University, Jinan 250357, China*

Correspondence should be addressed to You Wu Liu; lyw@fjsmu.edu.cn

Received 22 October 2021; Revised 25 November 2021; Accepted 10 December 2021; Published 12 January 2022

Academic Editor: Qiangyi Li

This paper decomposes the routing process of industrial robot network using the application of analytic hierarchy process in decision-making. The influence of four factors, such as path length, data integrity, energy consumption, and receiving delay, on routing effect is analyzed. Simultaneous interpreting routes are selected to achieve the purpose of routing. Simulation results show that this method can more comprehensively consider the factors affecting routing and is superior to the existing methods in terms of energy consumption, data integrity, and transmission delay.

1. Introduction

The analytic hierarchy process, referred to as AHP, is a decision-making method that decomposes the elements always related to decision-making into objectives, criteria, schemes, and other levels and makes qualitative and quantitative analysis on this basis. This method is a hierarchical weight decision analysis method proposed by Satty, an American operations research scientist and professor of the University of Pittsburgh, in the early 1970s, when studying the topic of "power distribution according to the contribution of various industrial departments to national welfare" for the U.S. Department of defense, using the network system theory and multiobjective comprehensive evaluation method [1].

Analytic hierarchy process (AHP) refers to a systematic method that takes a complex multiobjective decision-making problem as a system, decomposes the objective into multiple objectives or criteria and then decomposes it into several levels of multiple indicators (or criteria and constraints), and calculates the hierarchical single ranking (weight) and total ranking through the qualitative index fuzzy quantitative method so as to be used as the objective (multiple indicators) and multischeme optimization decision-making [2].

Analytic hierarchy process decomposes the decision-making problem into different hierarchical structures according to the order of general objectives, subobjectives of each level, evaluation criteria, and specific standby investment scheme and then obtains the priority weight of each element of each level to an element of the upper level by solving the eigenvector of the judgment matrix. Finally, the weighted sum method is used to merge the final weight of each alternative scheme to the overall goal, and the best scheme is the one with the largest final weight [3].

Analytic hierarchy process is more suitable for decision-making problems with hierarchical and staggered evaluation indexes, and the target value is difficult to describe quantitatively [4].

According to the nature of the problem and the general goal to be achieved, the analytic hierarchy process decomposes the problem into different constituent factors and aggregates and combines the factors according to different levels according to the correlation, influence, and subordinate relationship between the factors to form a multi-level analysis structure model, so as to finally make the problem boil down to the lowest level (schemes and measures for decision-making) relative to the highest level (general goal): the determination of the relative important weight or the arrangement of the relative advantages and disadvantages [5].

As early as the last century, traditional sensors, as an important medium connecting the physical world and the electronic world, played an important role in the fields of industry and agriculture, medical and health care, military, and national defense. Traditional robots are mainly composed of sensitive elements, conversion elements, and basic circuits. As the most basic and important means of information acquisition, their function is equivalent to human facial features to perceive external information. However, the degree of miniaturization, networking, and intelligence of traditional robots is very limited because their data processing and analysis capabilities are extremely limited. In recent years, with the rapid development and maturity of industrial communication, microelectromechanical systems (MEMS), and very large-scale integrated circuits (VLSI), modern robots have the ability of perception and communication and embark on the development direction of miniaturization, intelligence, and networking, Its most typical representative is the industrial robot node (also known as robot node) [6–9].

These robot nodes with certain sensing, computing, and communication capabilities are distributed in a specific area; cooperate to monitor, perceive, and process the data in the network in real time through self-organization; and transmit the data to the sink node (sink node) through multihop through short-range industrial communication to form a network integrating information sensing, information processing, and information transmission; we call it industrial robot networks (IRNs). If the Internet constitutes a logical information world and changes the way of communication and communication between people, IRNs will integrate the real physical world and the logical information world, which will change the way of interaction between human and nature [10–12].

As a new technology, IRN technology is promoting scientific and technological development and social progress. It is related to national social and economic security. It has become the commanding point of international competition and has attracted great attention from military departments, academia, and industry all over the world. IRNs play an important role in the control, computing, communication, surveillance, intelligence, reconnaissance, and positioning systems in the military command system.

2. Related Works

IRNs is data centric, and its goal is to transmit data from the network to sink nodes (sink nodes) and then process it accordingly. Therefore, how to efficiently and energy-saving transmit the data in the network to the sink node is one of the key technologies of IRNs research. Due to the limited storage, computing, and communication capabilities of industrial robot networks, it will bring some challenges to data transmission. In traditional industrial networks, data transmission usually goes through the process of compression before transmission. There are two kinds of traditional data compression algorithms: lossless compression and loss compression. Lossless compression is to reduce the amount of data transmission without destroying the integrity of information. Loss compression allows the loss of some information to minimize the amount of data transmission. At present, many loss and lossless data compression algorithms have been developed. However, the application of these algorithms in IRNs is limited. Because the processing memory of robot networks is very limited, some compression algorithms with high complexity cannot be directly applied to IRNs. In addition, some compression algorithms requiring frequent read and write operations will consume a lot of energy of robot nodes and cannot effectively save energy; therefore, these algorithms cannot be well applied to IRNs. Similarly, there are many transport layer schemes designed for traditional industrial networks, but most of them are not suitable for IRNs, because the node energy in IRNs is very limited, while the node energy resources of traditional industrial networks are relatively rich. The end-to-end communication of these traditional transport layer protocols will lead to a waste of resources in IRNs. Therefore, IRNs need effective data transmission schemes to collect data efficiently and energy saving. However, due to the limited computing, storage and communication resources of IRNs, many existing data compression and transmission schemes are difficult to be applied to IRNs, and there is no effective solution to the data transmission problem of IRNs. Therefore, the research on data compression and transmission schemes in IRNs is a challenging frontier research field and has become an important aspect of the research on Key Technologies of IRNs [13].

In traditional industrial LAN, the main goal of routing protocol is to provide high-quality service and make fair and efficient use of network bandwidth, such as finding paths with small delay or paths with large bandwidth. The quality of service is the primary factor considered in traditional networks. The main differences between industrial robot networks and traditional industrial networks are as follows: energy limitation. The energy of industrial robot network nodes is limited and difficult to supplement, and applications often require the network to have a long life. Therefore, energy saving is the primary factor to be considered in industrial robot network communication. Apply correlation. The application scenarios of robot networks are diverse, and the data transmission characteristics of different applications may be quite different. It is difficult to have a general routing protocol to meet the needs of all applications, and the communication protocol has strong application relevance. The network scale is large. The data of robot network nodes is often large. Such a large-scale deployment puts forward high requirements for routing. The node capacity is limited, so it is difficult to globally optimize the whole network, and the corresponding route can only be selected according to the local information [14].

In the energy-saving research of routing protocols in industrial robot networks, it is not simply required to reduce the total energy consumption, but more importantly, the overall energy consumption of the whole network and the uniform distribution of energy consumption. Because the purpose of energy saving is to prolong the service life of industrial robot networks, if the total energy consumption is reduced, but it is too concentrated on a few nodes, resulting in premature energy depletion of hot nodes, it will also shorten the system life. In the research of industrial robot network routing protocol, the main ways of energy saving are as follows: selecting the path with more residual energy for transmission, to balance the energy consumption of network transmission and avoid excessive concentration of energy consumption, which will affect the service life of the whole network; nodes sleep regularly. In industrial robot networks, due to the large number of nodes, there are often more redundant nodes, so that some nodes sleep does not affect the application needs of the whole network. Therefore, nodes can work alternately to prolong the lifetime of the whole network; transmission power control, which optimizes the network topology to reduce transmission energy consumption by adjusting the power of data sent by nodes; data fusion in the transmission process is used to reduce energy consumption. For example, in the cluster network, the cluster head node processes the data in the cluster to reduce the amount of data transmitted in the next step. In the research of routing protocols and protocols, it is mentioned to reduce communication energy consumption through periodic sleep. There are some differences between the two kinds of sleep. In the protocol, the node sleeps regularly to reduce the energy consumption of idle monitoring. While sleeping regularly, it still undertakes the task of data transmission. If the node stops working, it will affect the performance of the whole network. In the routing protocol, nodes sleep alternately because there are redundant nodes in the network. Some nodes sleep will not affect the overall performance of the network. Some redundant nodes can sleep to balance the network load and prolong the network life [15].

With the rapid development of industrial communication technology, microelectronics technology and embedded computing technology, miniaturized robot nodes with short-range industrial communication, storage and embedded computing capabilities become possible. Industrial robot networks (IRNs) are composed of many robot nodes distributed in specific areas and with certain computing, storage, and communication capabilities. There are two types of nodes: one is ordinary node, which is responsible for data collection and forwarding; one is the sink node, which is responsible for the collection and processing of the whole data in the network. A robot network consists of multiple ordinary nodes and at least one sink node (sink node). The nodes form a network through self-organization. At present, industrial robot networks are widely used in environmental monitoring [16], health monitoring [17], smart home [18] and intelligent transportation [19], and they have a wide application prospect. In industrial robot networks, each node can only communicate with nearby nodes with several hops, and the data can reach the sink node (sink node) only after multihop forwarding through the intermediate node. When the rate of data packets received by the robot node is greater than its forwarding or scheduling rate, the excess data packets need to be cached; when the queue of cached packets is full, the excess packets will be discarded, which leads to congestion in industrial robot networks. The core of data transmission is how to solve the congestion problem, that is, congestion control mechanism. If the congestion is not controlled, it will increase the packet delay, reduce the network throughput, and waste energy. Therefore, in the process of data transmission, how to effectively reduce congestion is an important aspect of industrial robot network technology research.

There are two main indicators to measure the effectiveness of congestion control protocols. One is the quality of service, including throughput and delay. The second is weighted fairness [20]. The current majority congestion control protocol mainly considers the quality of service and seldom considers how to ensure the weighted fairness of data transmission. Simultaneous interpreting the number of packets generated by Sink nodes receiving different robot nodes is directly proportional to the importance of robot nodes. Ensuring weighted fairness can enable sink nodes to obtain more packets from important data sources. However, the existing congestion control protocols do not fully consider the quality of service and weighted fairness. Xiong et al. [21, 22] mainly consider how to improve the efficiency of data transmission, that is, quality of service, without involving weighted fairness. Wu et al. [23, 24] consider not only the quality of service, but also fairness, but only simple fairness, that is, ensure that sink nodes receive as many packets as each node in a certain period. Although Reference [25] considers service quality and weighted fairness, it is only a heuristic method without specific weighted fairness measurement and theoretical result guarantee. In view of the aforementioned shortcomings, we propose a new congestion control protocol, which not only considers the quality of service of data transmission but also gives a weighted fairness measure for the first time and gives a lower bound in theory.

Industrial robot networks (IRNs) are data-centric networks. Data transmission technology is an important aspect of IRNs key technology research, and congestion control technology is the most basic and core part of data transmission technology. Congestion control is essentially a problem of how to deal with node cache space and shared bandwidth. Any problem in these two aspects will lead to network congestion, resulting in data loss, delay and energy waste. Because the computing, storage, and communication resources of nodes in IRNs are very limited, the energy efficiency of nodes must be considered when designing congestion control protocol. This feature makes the previous traditional network congestion control technology not suitable for IRNs. Therefore, it is necessary to design a new congestion control protocol according to the characteristics of IRNs. At present, many universities and research institutes at home and abroad have carried out relevant research on this.

3. Analytic Hierarchy Process

Due to the limited computing power, storage capacity, communication capacity, and energy of industrial robot nodes, compared with the routing algorithms of traditional networks, the routing algorithms of industrial robot networks have the following characteristics: (1) save node energy consumption and prolong the lifetime of the whole network; (2) reliability and integrity of data reception and transmission; (3) timeliness of data reception. Therefore, there are the following types of current routing algorithms: data-based routing algorithms, which name metadata. Nodes that have received source data do not need to continue to propagate, saving energy. However, when the surrounding nodes that generate or receive data do not need the data, the data will not be forwarded, and the routing reliability is insufficient; location-based routing algorithm, which uniformly encodes all network nodes and routes according to geographical location. The data transmission delay is small, but the unbalanced traffic is easy to lead to the failure of some nodes, thus damaging the network connectivity; LEACH algorithm, this kind of algorithm node transmits the data to the cluster head through one hop communication, and the cluster head also transmits the fused data to the aggregation node through one hop communication. The transmission delay is small, but the cluster head is required to have strong communication ability. The aforementioned algorithms do not fully consider the path length, data integrity, energy consumption, reception delay, and other factors during data transmission. Therefore, the transmission path obtained may not be optimal under different influence weights.

Analytic hierarchy process (AHP) is a decision-making method that uses multiple schemes to solve objective problems. Its core feature is the reasonable combination of qualitative decision-making and quantitative decision-making and the hierarchical and quantitative process of decision-making according to the law of human thinking and psychology. The basic idea of analytic hierarchy process is to decompose the problem first and then synthesize it: first, carry out hierarchical analysis on the problem to be solved, decompose the problem into multiple different constituent factors according to the nature of the problem and the overall goal to be achieved, and gather and combine the factors according to different levels according to the interaction and subordination between the factors; constitute a structural model of multilevel analysis; and finally, reduce the problem to the weight of the relative importance of the bottom layer relative to the top layer or the relative order of advantages and disadvantages.

In this paper, according to the application of AHP to the ranking of the advantages and disadvantages of decision-making problems, the process of industrial robot routing is regarded as a decision-making problem. Through the hierarchical analysis of various factors affecting routing, the ranking of the advantages and disadvantages of multiple transmission paths is obtained, to select a relatively good transmission path. As shown in Figure 1, the system model is an industrial robot network model with seven nodes. The initial node is a, the destination node is g, and the transmission paths 1, 2, and 3 are three optional transmission paths, respectively. The path length, data integrity, energy consumption, and reception delay of the three transmission paths are different.

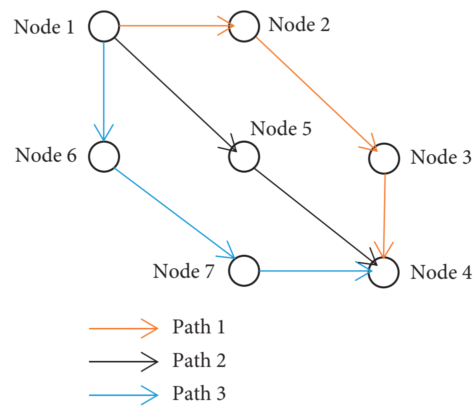

Figure 1: The system model with 7 nodes.

4. Path Selection Process

Different weights are set for path length, data integrity, energy consumption, reception delay, and other factors. For example: 1. Generate the judgment matrix of evaluation indicators. 2. Sort the hierarchy in single order.

The details are as follows:

For the target layer, the relative importance of the four factors of the criterion layer, namely path length (C1), data integrity (C2), energy consumption (C3), and reception delay (C4), is formed into a judgment matrix. The specific composition method is to compare the importance of elements to determine the weight value of the criterion for the target. The 1–9 scale method is adopted for comparison, as shown in Table 1:

For the comparison factor, it is considered that the same importance is 1 : 1, and the strong importance is 9 : 1. You can also take the intermediate value of 6 : 1 and compare them in pairs. Fill in and arrange the obtained values to form the judgment matrix A:

$$A = \begin{pmatrix} 1 & 1/2 & 4 & 3 \\ 2 & 1 & 7 & 5 \\ 1/4 & 1/7 & 1 & 1/2 \\ 1/3 & 1/5 & 2 & 1 \end{pmatrix}. \quad (1)$$

Then all scheme layer judgment matrices relative to different criteria are constructed, which is constructed using the ratio of the actual data measured by different paths in the scheme layer. For example, the path length of transmission path 1 is $a = 100$ m, and the transmission distance of path 2 is $b = 50$ m. Take $a : b = 2$ and fill it in the judgment matrix. Examples are as follows: relative to path length:

$$B_1 = \begin{pmatrix} 1 & 2 & 1/3 \\ 1/2 & 1 & 2 \\ 3 & 1/2 & 1 \end{pmatrix}. \quad (2)$$

Relative to data integrity:

Table 1: 1–9 proportional scale method and its meaning.

Scale	Meaning
1	Both elements have the same importance
3	The former is a little more important than the latter
5	The former is more important than the latter
7	The former is obviously more important than the latter
9	The former is absolute important than the latter
2, 4, 6, 8	Represents the intermediate value of the above adjacent judgment
$1/n$	If the importance ratio of element i to element j is n, the importance ratio of element j to element i is $1/n$

$$B_2 = \begin{pmatrix} 1 & 1/3 & 1/8 \\ 3 & 1 & 1/3 \\ 8 & 3 & 1 \end{pmatrix}. \quad (3)$$

Relative to energy consumption:

$$B_3 = \begin{pmatrix} 1 & 1 & 3 \\ 1 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{pmatrix}. \quad (4)$$

Relative to transmission delay:

$$B_4 = \begin{pmatrix} 1 & 3 & 4 \\ 1/3 & 1 & 1 \\ 1/4 & 1 & 1 \end{pmatrix}. \quad (5)$$

Single ranking of levels refers to the ranking of the importance of each factor in this level for a factor in the previous level. The specific calculation method is as follows: relative judgment matrix B, and the calculation meets the requirements.

$$BW = \lambda_{\max} W. \quad (6)$$

In formula (6), $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix B and W is the normalized eigenvector relative to $\lambda_{\max}$. The component ω_i of W is the weight of the corresponding element for single sorting shown in Table 2.

Definition 1. weight: the variable Z is expressed as a linear combination $z = w_1 x_1 + w_2 x_2 + \cdots + w_n x_n$ of variables $x_1, x_2, \ldots, x_n$, where $w_i > 0$, $\sum_{i=1}^{n} w_i = 1$ and $w_1, w_2, \ldots, w_n$ is called the weight of each factor relative to the target Z, $w = (w_1, w_2, \ldots, w_n)^T$ is called the weight vector.

(1) Firstly, the maximum eigenvalue and eigenvector of the judgment matrix A are obtained. Normalize each column vector of the judgment matrix A: $\tilde{w}_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij}$.

① Sum by line to $\tilde{w}_{ij}$ get: $\tilde{w}_i = \sum_{i=1}^{n} \tilde{w}_{ij}$.
② Normalize $\tilde{w}_i$ to $\tilde{w}_i = \tilde{w}_i / \sum_{i=1}^{n} \tilde{w}_i$, $w = (w_1, w_2, \ldots, w_n)^T$ is the approximate eigenvalue (weight vector) of the judgment matrix A.
③ The approximate value of the maximum eigenvalue $\lambda = 1/n \sum_{i=1}^{n} (Aw)_i / w_i$ is obtained. Namely,

$$A = \begin{pmatrix} 1 & 1/2 & 4 & 3 \\ 2 & 1 & 7 & 5 \\ 1/4 & 1/7 & 1 & 1/2 \\ 1/3 & 1/5 & 2 & 1 \end{pmatrix} \longrightarrow \begin{pmatrix} 0.279 & 0.229 & 0.286 & 0.315 \\ 0.558 & 0.598 & 0.5 & 0.526 \\ 0.070 & 0.085 & 0.071 & 0.053 \\ 0.093 & 0.120 & 0.143 & 0.105 \end{pmatrix} \longrightarrow \begin{pmatrix} 1.109 \\ 2.182 \\ 0.279 \\ 0.461 \end{pmatrix} \longrightarrow \begin{pmatrix} 0.277 \\ 0.546 \\ 0.070 \\ 0.115 \end{pmatrix} = w,$$

$$Aw = \begin{pmatrix} 1 & 1/2 & 4 & 3 \\ 2 & 1 & 7 & 5 \\ 1/4 & 1/7 & 1 & 1/2 \\ 1/3 & 1/5 & 2 & 1 \end{pmatrix} \begin{pmatrix} 0.277 \\ 0.546 \\ 0.070 \\ 0.115 \end{pmatrix} = \begin{pmatrix} 1.175 \\ 2.165 \\ 0.272 \\ 0.456 \end{pmatrix}, \quad (7)$$

$$\lambda = \frac{1}{4}\left(\frac{1.175}{0.277} + \frac{2.165}{0.546} + \frac{0.272}{0.070} + \frac{0.456}{0.115}\right) = 4.014,$$

Table 2: The parameters of the random consistency index RI.

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

then the maximum eigenvalue $\lambda_{max} = 4.014$ is obtained, and the eigenvector is $w = (0.277, 0.546, 0.070, 0.115)^T$.

(2) The maximum eigenvalue and weight vector of the judgment matrix of each influencing factor are calculated. According to the calculation method of judgment matrix A, the maximum characteristic root and weight vector of each influencing factor can be obtained as follows:

① Relative to the path length B_1, $\lambda_{max(1)} = 3.010$ the eigenvector is $w_1 = (0.298, 0.333, 0.370)^T$.
② Relative to data integrity B_2, $\lambda_{max(2)} = 3.002$ the eigenvector is $w_2 = (0.082, 0.236, 0.682)^T$.
③ Relative to energy consumption B_3, $\lambda_{max(3)} = 3$ the eigenvector is $w_3 = (0.429, 0.429, 0.142)^T$.
④ Relative to the transmission delay B_4, $\lambda_{max(4)} = 3.009$ the eigenvector is $w_4 = (0.633, 0.193, 0.750)^T$.

(3) Consistency inspection. The judgment matrix is usually inconsistent. In order to use the eigenvector of its corresponding Eigen root as the weight vector of the compared factor, an allowable inconsistency range should be limited. The method for determining the scope is as follows:

① Consistency index: $CI = \lambda - n/n - 1$ when $CI = 0$, A is consistent; The greater the CI, the more serious the inconsistency of A.
② Parameters of random consistency index RI.
③ Consistency ratio: $CR = CI/RI$ at that time $CR < 0.1$, the inconsistency degree of A is within the allowable range. At this time, the feature vector of a can be used as the weight vector. According to the maximum eigenvalue $\lambda_{max} = 4.014$ of A, $CI = (\lambda_{max} - n)/n - 1 = (4.014 - 4)/4 - 1 = 0.00467$ the average random consistency index RI can be found by looking up the table, so as to test the consistency of the matrix: $CR = CI/RI = (0.00467/0.90) = 0.00519 < 0.1$. Similarly, for the second level, the consistency test of the four judgment matrices of path length, data integrity, energy consumption, and transmission delay passed.
④ Form a matrix for column vectors w_1, w_2, w_3, w_4:

$$w_k = (w_1, w_2, w_3, w_4) = \begin{pmatrix} 0.298 & 0.082 & 0.429 & 0.633 \\ 0.333 & 0.236 & 0.429 & 0.193 \\ 0.370 & 0.682 & 0.142 & 0.750 \end{pmatrix}. \tag{8}$$

⑤ Get the total ranking of the hierarchy. The ranking vector of each scheme priority is as follows:

$$W = w \cdot w_k = \begin{pmatrix} 0.298 & 0.082 & 0.429 & 0.633 \\ 0.333 & 0.236 & 0.429 & 0.193 \\ 0.370 & 0.682 & 0.142 & 0.750 \end{pmatrix} \begin{pmatrix} 0.277 \\ 0.546 \\ 0.070 \\ 0.115 \end{pmatrix} = \begin{pmatrix} 0.231 \\ 0.273 \\ 0.570 \end{pmatrix}. \tag{9}$$

Decision result: the preferred transmission path is P_3, followed by P_2 and P_1.

5. Simulation Results Analysis

MATLAB software is used for simulation, and the node position is fixed. The simulation conditions are set as follows according to literature [15]:

(1) The nodes are fixedly distributed at 1000 m × 1000 m.
(2) The number of nodes is $n = 9$;
(3) Select 5 fixed transmission paths.

The simulation scenario is shown in Figure 2. The industrial robot routing path is simulated. The initial node is the leftmost lower node of the plane, and the endpoint is the rightmost upper node of the plane. There are five alternative transmission paths: P_1, P_2, P_3, P_4, P_5.

The parameters of each path are set as follows:

(1) The transmission path length is calculated according to the Euclidean distance between coordinates $d = d + \sqrt{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2}$;
(2) The data integrity is randomly selected between 40%–80%;
(3) Transmission energy consumption is 1000 J–2000 J randomly selected;
(4) The transmission delay is randomly selected between 1 s–10 s. Table 3 shows the comparison of various indicators of path selection by analytic hierarchy process and compass method.

It can be seen from Table 3 that in the industrial robot network deployed at the same node, the path generated by analytic hierarchy process has better data integrity, less energy consumption, and shorter transmission delay than the path selected in literature [16]. The path generated by analytic hierarchy process is larger than that generated by

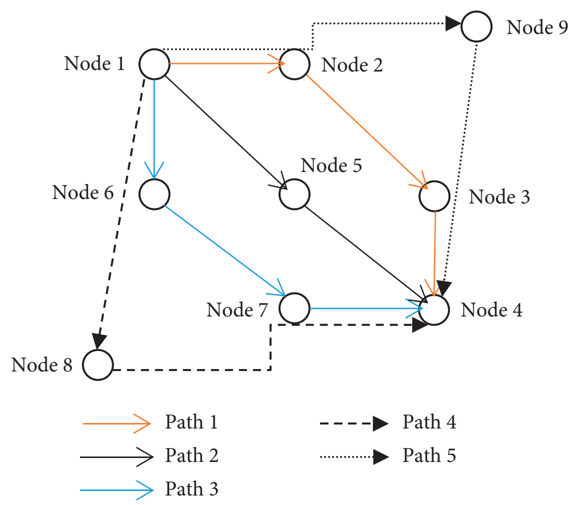

FIGURE 2: Nodes distribution.

TABLE 3: Parameters of each path.

Transmission path	Path length (m)	Data integrity (%)	Energy consumption (J)	Transmission delay (s)
P_1 (AHP)	454	79	1264	3
P_2	534	53	1443	5
P_3	457	61	1876	6
P_4	344	75	1724	4
P_5	786	67	1657	7

compass algorithm, but the transmission energy consumption and transmission delay are smaller than that of compass algorithm, and the data integrity is higher than that of compass algorithm. This is because the analytic hierarchy process considers the influencing factors of the routing process, while the compass method only considers the transmission path length.

6. Conclusion

In this paper, the application of analytic hierarchy process in decision-making is used to realize the simultaneous interpretation of industrial robot routing process. Four simultaneous interpreting factors, such as path length, data integrity, energy consumption, and receiving delay, are analyzed, and the relative order of different transmission paths is obtained to achieve the purpose of routing. Simulation results show that this method can more comprehensively consider the factors affecting routing and is superior to compass method in terms of energy consumption, data integrity, and transmission delay.

Data Availability

The dataset can be accessed upon request to the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

This research was supported by the Program of Fujian Science Foundation (no. 2020J01925), the 2019 Education Research Project for Young and Middle-Aged Teachers of Fujian Provincial Department of Education (no. JAT190721), Scientific Research and Development Fund of Sanming University in 2019 (no. B201934), 2019 Scientific Research Project for Middle-Aged and Young Teachers Education of Fujian Provincial Department of Education (no. JAS19335), Scientific Research and Development Fund of Sanming University in 2019 (no. A201904), Digital Fujian Research Institute for Industrial Energy Big Data, and IOT Application Engineering Research Center of Fujian Province Colleges and Universities.

References

[1] J. Zhang, X. Hu, Z. Ning et al., "Energy-latency tradeoff for energy-aware offloading in mobile edge computing networks," *IEEE Internet of Things Journal*, vol. 5, no. 4, pp. 2633–2645, 2018.

[2] R. Tang, X. Qian, and X. Yu, "On virtual force algorithms for coverage optimal node deployment in mobile sensor networks via the two-dimensional yukawa crystal," *International Journal of Distributed Sensor Networks*, vol. 15, p. 9, 2019.

[3] X. Deng, Z. Yu, R. Tang, X. Qian, K. Yuan, and S. Liu, "An optimized node deployment solution based on a virtual spring force algorithm for wireless sensor network applications," *Sensors*, vol. 19, p. 8, 2019.

[4] Q. Li, Q. Yi, R. Tang, X. Qian, K. Yuan, and S. Liu, "A hybrid optimization from two virtual physical force algorithms for

dynamic node deployment in WSN applications," *Sensors*, vol. 19, no. 3, 2019.
[5] S. Pengju, J. Ma, F. Tao, Z. Fu, and S. Lei, "Energy efficient barrier coverage with probabilistic sensors in wireless sensor networks," *IEEE Sensors Journal*, vol. 20, no. 10, pp. 5624–5633, 2020.
[6] P. Singh and Y.-C. Chen, "Sensing coverage hole identification and coverage hole healing methods for wireless sensor networks," *Wireless Networks*, vol. 26, no. 3, pp. 2223–2239, 2020.
[7] F. Yan, W. Ma, F. Shen, W. Xia, and L. Shen, "Connectivity based k-coverage hole detection in wireless sensor networks," *Mobile Networks and Applications*, vol. 25, no. 2, pp. 783–793, 2020.
[8] A. T. Ipek, "DiCDU: distributed clustering with decreased uncovered nodes for WSNs," *IET Communications*, vol. 14, no. 6, pp. 974–981, 2020.
[9] S. Nora, B. Ahcene, E. Reinhardt et al., "Maximum lifetime target coverage in wireless sensor networks," *Wireless Personal Communications*, vol. 111, no. 3, pp. 1525–1543, 2020.
[10] M. Mohammad and O. Suat, "Towards coverage aware fuzzy logic based faulty node detection in heterogeneous wireless sensor networks," *Wireless Personal Communications*, vol. 111, no. 1, pp. 581–610, 2020.
[11] Z. Ning, X. Hu, Z. Chen et al., "A cooperative quality-aware service access system for social Internet of vehicles," *IEEE Internet of Things Journal*, vol. 5, no. 4, pp. 2506–2517, 2018.
[12] K. Li, Y. Feng, D. Chen, and S. Li, "A global-to-local searching-based binary particle swarm optimisation algorithm and its applications in WSN coverage optimisation," *International Journal of Sensor Networks*, vol. 32, no. 4, pp. 197–208, 2020.
[13] F. Ahmad, G. Christophe, H. Mohammed, and H. Mourad, "Energy efficiency and coverage quality management for reliable diagnostics in wireless sensor networks," *International Journal of Sensor Networks*, vol. 32, no. 3, pp. 127–138, 2020.
[14] J. Wang and H. Guo, "Virtual force field coverage algorithms for wireless sensor networks in water environments," *International Journal of Sensor Networks*, vol. 32, no. 3, pp. 174–181, 2020.
[15] X. Hu, J. Cheng, M. Zhou et al., "Emotion aware cognitive system in multicchannel cognitive radio ad hoc networks," *IEEE Communications Magazine*, vol. 56, no. 4, pp. 180–187, 2018.
[16] J. Xiong, R. Bi, M. Zhao, J. Guo, and Q. Yang, "Edge-assisted privacy-preserving raw data sharing framework for connected autonomous vehicles," *IEEE Wireless Communications*, vol. 27, no. 3, pp. 24–30, 2020.
[17] Y. Tian, Z. Wang, J. Xiong, and J. Ma, "A blockchain-based secure key management scheme with trustworthiness in DWSNs," *IEEE Transactions on Industrial Informatics*, vol. 16, no. 9, pp. 6193–6202, 2020.
[18] J. Xiong, X. Chen, Q. Yang, L. Chen, and Z. Yao, "A task-oriented user selection incentive mechanism in edge-aided mobile crowdsensing," *IEEE Transactions on Network Science and Engineering*, vol. 7, no. 4, pp. 2347–2360, 2020.
[19] J. Xiong, R. Ma, L. Chen et al., "A personalized privacy protection framework for mobile crowdsensing in IIoT," *IEEE Transactions on Industrial Informatics*, vol. 16, no. 6, pp. 4231–4241, 2020.
[20] J. Xiong, M. Zhao, M. Z. A. Bhuiyan, L. Chen, and Y. Tian, "An AI-enabled three-party game framework for guaranteed data privacy in mobile edge crowdsensing of IoT," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 2, pp. 922–933, 2021.
[21] J. Xiong, J. Ren, L. Chen et al., "Enhancing privacy and availability for data clustering in intelligent electrical service of IoT," *IEEE Internet of Things Journal*, vol. 6, no. 2, pp. 1530–1540, 2019.
[22] J. Chen, Y. Tian, W. Ma, Z. Mao, and Y. Hu, "Scale Channel Attention Network for Image Segmentation," *Multimedia Tools and Applications*, vol. 80, pp. 1–17, 2020.
[23] D. Wu, Z. Zhang, S. Wu, J. Yang, and R. Wang, "Biologically inspired resource allocation for network slices in 5G enabled Internet of things," *IEEE Internet of Things Journal*, vol. 6, no. 6, pp. 9266–9279, 2019.
[24] D. Wu, J. Yan, H. Wang, and R. Wang, "User-centric edge sharing mechanism in software-defined ultra-dense networks," *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 7, pp. 1531–1541, 2020.
[25] R. Wang, H. Liu, H. Wang, Q. Yang, and D. Wu, "Distributed security architecture based on block chain for connected health: architecture, challenges, and approaches," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 30–36, 2019.