Constructing the Electronic Countermeasures System Architecture Based on Case-Based Reasoning and Bayesian Inference

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Abstract. In order to promote the quality of electronic countermeasures system architecture, this paper presents a methodology for constructing the electronic countermeasures system architecture based on case-based reasoning and Bayesian inference. The methodology described history cases by CPN model, established the largest similarity case and feasibility space by combining the CPN color set and k-means algorithm, and then proposed the optimizing orderings of variables of Bayesian by the LFS (Legal Firing Sequence) of CPN model and maximum information entropy, learned the Bayesian networks structure by K2 algorithm using the result of orderings of variables. At last, this paper concluded the electronic countermeasures system architecture tactics and discussed the way of reasoning for constructing the electronic countermeasures system architecture.

1. Introduction
The construct of electronic countermeasures system architecture is the modeling description and scientific method for programming electronic countermeasures system architecture, which is important for the electronic countermeasures operations. Generally, there are some method for constructing system architecture, such as the object oriented method, the structured approach, the structure evolvement reuse method and so on[1][2][3]. However, no matter which method we choose, since the metric criterion and rules of analysis are difficult for the quantitative analysis, and there is still no unified standard, we would get the different results for the electronic countermeasures system architecture because of the different metric criterion, rules of analysis and standard.

In this paper, we consider the problem of construct of electronic countermeasures system architecture form the recorded data, and present a methodology for constructing the electronic countermeasures system architecture based on case-based reasoning and Bayesian inference. The main ideas of the methodology include two aspects: First, we establish the largest similarity case and feasibility space by combining the CPN color set and k-means algorithm, then reduce the feasibility space. Second, we get the optimizing orderings of variables by the LFS (Legal Firing Sequence) of CPN model and maximum information entropy, and learn the Bayesian nets structure by the K2 algorithm using the optimizing orderings of variables, and then construct the electronic countermeasures system architecture by the Bayesian inference.
2. Description and Indexing for the case of electronic countermeasures system architecture

2.1. Description of the case of electronic countermeasures system architecture

In order to better description of electronic countermeasures system architecture, we description the case by the CPN (colored Petri net) model. According to the methods in literature [4] and literature [5], the CPN top-level model of the case can be established, and its graphical description can be shown in Figure 1 (the description of token is omitted in Figure 1).

![Top-level CPN model for the case of electronic countermeasures system architecture](image)

Fig. 1 Top-level CPN model for the case of electronic countermeasures system architecture

In fact, for electronic targets, more attention is paid to the signal-related features of the initial situation, such as target type, parameters, discovery time and so on, and these features are described by the color set in the CPN model, which is represented by \( \Sigma_0 \). Therefore, the description of the electronic target can be simplified to the description of the color set, which presented by \( CD = \Sigma_0 \). The description of the electronic countermeasures system architecture is the description of the case, that is \( CR = CPN_{ECSA} \), where \( CPN_{ECSA} \) is the CPN model of the substitution transition \( ECSA \) in Figure 1. The substitution transition \( JudgeProcess \) is the process of judging the result of electronic jamming in Figure 1. When electronic jamming can be implemented on an electronic target, the token corresponding to the target is sent to the place \( OperationResult \). Therefore, the token number of the place \( OperationResult \) can be used to represent the description of the case result, that is

\[
CR = \frac{K_{y'}(P_{OperationResult})}{K_{y'}(P_{TargetToSend})}, \quad K_{y'}(P_{OperationResult})
\]

represents the token number of the place \( ECR\) when it is in the reachable markings, which presented by \( M_\text{matchProcess} \rightarrow \cdot K_{y'}(P_{TargetToSend}) \) represents the total number of tokens in the initial state, which belong to color set \( \Sigma_0 \), and it also describe the number of initial electronic targets.

2.2. Case retrieval based on CPN model Case

Case retrieval is the process of retrieving similar cases from the case database based on the input of relevant information about the problem. It can usually be divided into the retrieval of the largest similar case and the set of similar cases. Case retrieval based on the CPN model is a process of retrieving similar case sets, as well as a process of establishing a sample space. Then the case set is clustered through the k-means algorithm and divided into \( k \) data clusters, and the average value of each data cluster is the first-level search for the search object, so as to determine the data cluster which is the most similar to the search condition and record it as \( \Phi(\text{Index}) \).
3. Construction of Electronic Countermeasures System Architecture Based on Bayesian inference

3.1. Construction of feasibility space

The construction of the feasibility space is mainly based on the retrieval space \( \Phi(\text{Index}) \). Expand the retrieval space \( \Phi(\text{Index}) \) by change the electronic countermeasures system architecture description model (\( CPSA \) model) of each case.

Let \( \Phi(ECSA) \) is the space of expanded by space \( \Phi(\text{Index}) \), \( N \) is the the dimensions of the space \( \Phi(ECSA) \). Generally speaking, \( N \) are relatively large and need to be reduced. Space \( \Phi(ECSA) \) reduction mainly consists of two steps. The first step is to determine the constraints based on the rules of electronic countermeasures to limit the scale of change for \( CPSA \), which is based on the rules of electronic countermeasures to refine the relevant rules into constraints suitable for the description of the CPN model. The second step is to reduce accessibility, boundedness, and consistency through static analysis of the CPN model, which is can be to determine through the LFS analysis [6][7].

After static analysis based on electronic countermeasures rules and CPN model, the reduced space \( \Phi(ECSA) \) is the feasibility space.

3.2. Bayesian network structure learning

This paper use “task completion” as a variable, calculate the posterior probability of the variable by Bayesian inference, and select the CPN model that maximizes the posterior probability of the variable “task completion” to realize the construction of electronic countermeasures system architecture. This paper makes full use of the transition sequence results of the CPN model, and proposes a hybrid Bayesian structure learning method based on the CPN transition sequence and K2 algorithm.

First, determines the variables of the Bayesian network and the corresponding relationship with the case. Second, according to the corresponding relationship between variables and cases, the CPN model of the largest similarity case is determined in the retrieval space \( \Phi(\text{Index}) \) and the reachability analysis is performed. According to the sequence of transition, the corresponding order of variable \( \rho \) is obtained. Usually, reachability analysis can be performed through LFS of Petri nets [12] [13] to determine the sequence of transition initiation. In the transition initiation sequence, the transition corresponding to the variable is ranked first, and the variable is ranked first. When sorting variables, if multiple variables correspond to the same substitution transition, the maximum information entropy method is used to determine the ranking [8][9].Third, take the case database data as a sample, according to the order of the variables \( \rho \), learn the Bayesian network structure through the K2 algorithm. Finally, the CPN model with the greatest posterior probability of variable “task completion” in the feasibility space \( \Phi(ECSA) \) is determined by Bayesian inference, which is also the realize construction of electronic countermeasures system architecture for the specific electronic target.

4. Test Results and Discussions

In order to test the methodology in application performance for the construction of electronic countermeasure system structure, two groups of experiments through a simulation system are carried out. In the two groups of experiments, the number and type of electronic countermeasures systems are all the same, and the mission are both to jamming two radars. The only difference is there are 10 variables for Bayesian net in group one and 15 variables in group two. Both groups of experiments obtained 10,000 simulation data, and each group data was randomly selected as a sample data, which its background would be the description of problem and its CPN model would be the description of the result. Then, 500, 1000, 5000, and 10,000 sets of data were selected as the historical case database for each group.
The number of errors in arcs is used as the number of errors in the final result, which is the sum of the number of missing arcs, the number of extra arcs and the number of arcs in the wrong direction. The results of the number of errors in arcs for two groups are shown in Table 1.

Table 1. The results of the number of errors in arcs for two groups

| set of data | number of missing arcs | number of extra arcs | number of arcs in the wrong direction | sum of the number of arc errors |
|-------------|------------------------|----------------------|---------------------------------------|-------------------------------|
| 500         | group one | group two | group one | group two | group one | group two | group one | group two |
| 2           | 2         | 0         | 1         | 0         | 1         | 0         | 2         | 4         |
| 1000        | group one | group two | group one | group two | group one | group two | group one | group two |
| 2           | 2         | 0         | 3         | 1         | 2         | 0         | 3         | 8         |
| 5000        | group one | group two | group one | group two | group one | group two | group one | group two |
| 2           | 2         | 1         | 3         | 2         | 1         | 0         | 4         | 9         |
| 10000       | group one | group two | group one | group two | group one | group two | group one | group two |
| 2           | 2         | 2         | 3         | 2         | 2         | 0         | 6         | 9         |

It can be seen from the experimental results that the method proposed in this paper works well on simulation data, and because the error number of each data volume is not very different, it can be used in various data volume situations. It is worth noting that the two sets of data have different selections of variables, which leads to significant changes in the number of arc errors. Therefore, the use of this method requires full consideration of the selection of variables, which is also the content of the next analysis and research.

5. Conclusion

By using historical data, this paper proposes an electronic countermeasures system architecture construction method based on case-based reasoning and Bayesian inference. This method uses the k-means algorithm to quickly construct the largest similar case and retrieval space, determines the variable sequence based on the CPN model transition sequence and the maximum information entropy method, and then uses the K2 algorithm to construct a Bayesian network, and finally realizes it through Bayesian network inference. According to the experimental results, this method is suitable for the construction of electronic countermeasures system architecture of various levels, and because of the different selections of variables leads to significant changes of results, the next step requires further analysis and research around the variable selection problem.

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