Design and Research of Bayesian Reasoning Method based on Wireless Intelligent Nodes

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Abstract: Aiming at the multi-attribute decision problem of networked ammunition, the research of intelligent decision method is carried out. Based on the tasks of blocking the key areas in wild, the main factors affecting the decision are analysed. According to the inherent logical relationship of each factor, a decision model based on Dynamic Bayesian Network (DBN) is proposed. In addition, in order to better verify the practical performance of the reasoning method, a simulation system including software and hardware is designed. The wireless intelligent node includes self-positioning module, communication module, detection module, signal processing module, feedback module, core processing module and power module. Software, used Visual Studio 2015 as the development platform, it is based on C# language and includes modules such as interactive display, communication and algorithm. Through the system test and semi-physical simulation experiments, the practicability and effectiveness of the reasoning method are verified, which proves that it can provide support for research and practical use.

1 INTRODUCTION

Networked ammunition is a new type of ammunition generated by the development of new technologies such as autonomous networks, situational awareness, and mission planning. It is a kind of smart weapon that contains multiple sensors, multiple damage modes, and multiple nodes to coordinate attacks. It can be manually deployed, rocket bombs and airborne dispensers, with the characteristics of small size, low cost and high efficiency. Multiple functions can be achieved, such as autonomous positioning, automatic alert, multi-mode detection, identification and tracking targets and attack decisions (Li Ming, Luo Guohua and Jiang Chunlan, 2017)

Both domestic and foreign research have made substantial progress and put into use, such as the US XM-7 "Spider" anti-infantry mine and XM1100 "Scorpion" intelligent ammunition (Zhao Yuqing, Niu Xiaomin, Wang Xiaobo and Xia Muquan, 2012), Russian M225 intelligent ammunition, German "Leap" intelligent ammunition. Comprehensively, they already have the ability to use in the battlefield. Each submunition is a decentralized and independent wireless intelligent node in networked ammunition, which is a decentralized information unit with sensing, communication and decision functions, which can realize information fast flow and sharing, interconnection and intercommunication (Chen Xiaoqing, 2019).

In the process of battlefield use, networked ammunition's functions and tasks are more and more complicated. The importance of how to make attack decisions is increasingly prominent. While Bayesian network (BN) theory is an effective way to solve uncertain problems, it is similar to human brain thinking logic and can be represented by directed acyclic graph (DAG). Dynamic Bayesian network (DBN) is an extension of the BN theory (Xiao Qinkun, Gao Song and Gao Xiaoguang, 2007). Due to the addition of time factors, in addition to the basic functions of BN, DBN also has the ability to process time series data (Ma Guopu, Sha Jichang, Chen Liangjun, Chen Chao and Jiang Xin, 2010). It has been fully applied in the fields of automatic driving, risk assessment and group robot. This paper focus on the actual task and uses Bayesian network as the knowledge framework to study the attack decision problem, in addition, a development system is carried out.

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2 SYSTEM COMPOSITION

The system includes a central node, parent nodes, sub nodes and a command terminal. The network topology is a single-center and multi-cluster network. The structure of the system is shown in Figure1. The node network status is randomly generated by the networking program. The central node collects the information of the nodes in the network and sends to the command terminal. And parent nodes and sub nodes are mainly used to detect and attack the target.

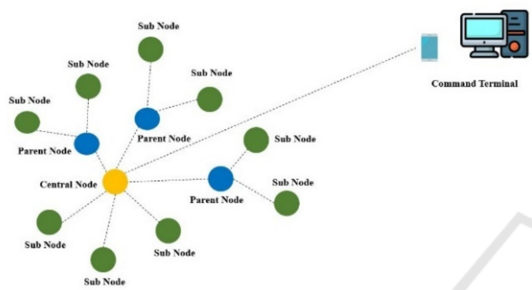

Figure 1. Structure of the system.

2.1 Wireless Intelligent Node

In order to facilitate the upgrade, the central node, parent nodes and sub nodes adopt a homogeneous and modular design, which are based on the universal development chips. The structure of wireless intelligent node is shown in Figure 2.

In order to simulate the ammunition's ESP warhead, the node contains four feedback modules including buzzer and LED lighting, which is convenient for observing in outdoor experiments. Self-positioning module consists of Beidou and GPS positioning chips, it is dual-mode design for improving reliability, especially in one signal weak condition or interference area. Detection module contains sound and vibration chips, due to low power consumption requirements, vibration is used as early warning signal, when the vibration signal reaches the threshold, the node starts the active sound detection mode to locate the targets. Communication module includes RF and WIFI chips. RF is used to transmit data between nodes and WIFI is used to communicate with command terminal.DSP chip is used for D/A conversion, filtering and feature extraction of two signals. The 32-bit ARM chip transmits data through the serial port between modules, self-tests, pre-sets target information, processes the location information. The node's working status can be conveniently observed through display module, which contains the LCD, such as "network completion", "alarm detecting", "attack target", etc. Power module consists of a 12V lithium battery and a voltage regulator circuit to supply power to each module of the node.

2.2 Terminal Software

The software used by the command terminal uses Visual Studio 2015 as the development platform, mainly based on the C# language. The software running process is shown in Figure 3.

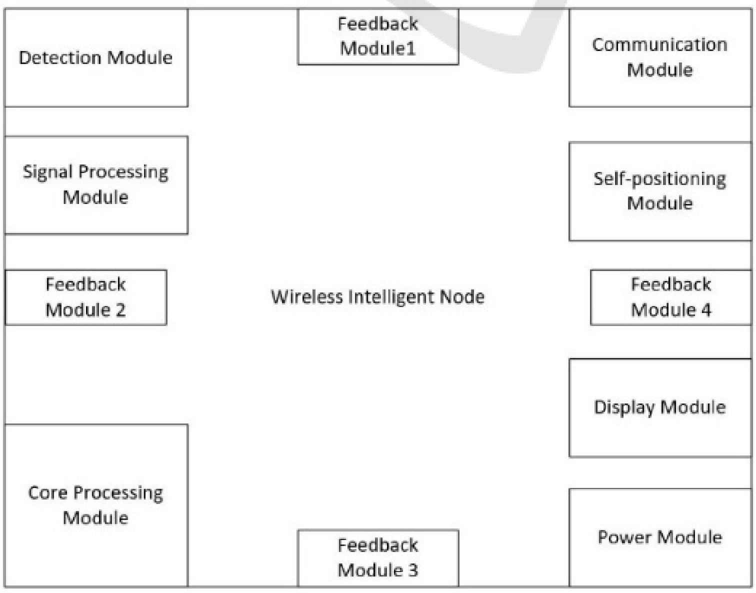

Figure 2. Structure of wireless intelligent node.

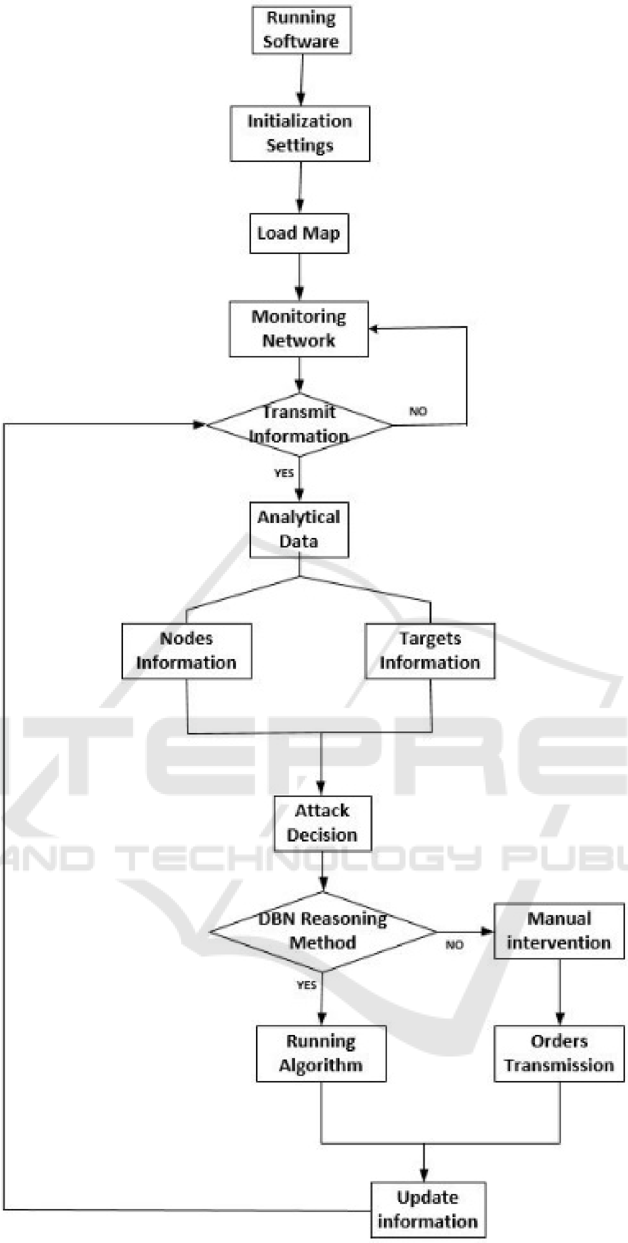

Figure 3. Running process of terminal software.

2.2.1 Display Interaction Module

The quality of the interface directly affects the user's efficiency (Zhao Lin, Zhang Lingtao, Wang Zan, Tian Guohui, Zhang Liang, 2018). The main interface uses full-screen layout to display geographic information, node location, network connectivity and target track, and text and voice prompts for node status and target status. The top of the screen is the function menu, and the left and right sides are "information" area and "control" area which can be hidden.

2.2.2 Communication Module

It is mainly used for information transmission between nodes and hardware in semi-physical simulation experiments, using multi-threading technology. Socket communication mode is adopted because it has the advantages of self-definable transmission data, small data volume, short transmission time and encryption (Wu Jinghua, Hao Xiaolong and Wang Haifeng, Gao He, 2018).

2.2.3 Algorithm Module

The DBN reasoning algorithm based on wireless intelligent nodes is written by MATLAB and saved as ".dll" format for C# calls.

3 DBN-BASED DICISION MODEL

The DBN theory overcomes the time dependence and computational difficulties of the rule-based system, and the networked ammunition attack decision process can be regarded as a discrete stochastic process. The DBN consists of observation variables and hidden variables, and uses probability distribution to describe causality (Yao Hongfei, Wang Hongjian, Lyu Hongli and Wang Ying, 2018). The attack decision model is constructed according to the DBN's characteristics and the tasks' characteristics. The battlefield's environment is complicated and changeable (Hunkar Toyoghu, Oya Ekin Karasan and Bahar Yetis Kara, 2011), to solve the attack problem, some assumptions need to be given.

3.1 Assumptions

The information transmission between nodes is smooth, and the central node can obtain global information.

The number of targets is less than the number of nodes, and each target is assigned at least one node for attack.

The detector's performance is so excellent that can get all the information of the targets in the detection distance.

Once the target is found, it is destroyed immediately.

3.2 Observation Variables

Multi-node fusion sound detection can calculate the number of targets, the angle between the target and the node, the target speed, and judge the target type according to its noise characteristics. The node can transport its working status through its own sensor, such as network status, battery power, and the remaining number of the warhead. The network status means that the node is a central node, a parent node or a child node, and the battery power represents the remaining capacity of the lithium battery, and the remaining number of the warhead represents the remaining number of the warhead under the angle corresponding to the target. In addition, the detection distance constraint and the attack distance constraint are also direct evidence. The observation variables of the attack decision model are shown in Table 1.

Table 1. Observation variables.

Variables	Meaning	Collection
TA	Target angel	AS1, AS2, AS3, AS4
TS	Target speed	HS, MS, LS
TT	Target type	TA, VE,
NP	Node battery power	EN, LO
NNS	Node network status	CE, PA, SU
NWR	Node warhead remain	0, 1
NWS	Node working status	N, I
DDC	Detect distance constraint	0, 1
ADC	Attack distance constraint	0, 1

TA = {AS1, AS2, AS3, AS4} indicates target angel. In order to speed up the calculation, four regions according to the warhead installation position are divided. The division of TA is shown in Figure 4. TS = {HS, MS, LS} represents the speed of targets which are discovered by the detector. TT = {TA, VE} is the type of ground targets, vehicle and tank are the mainly types currently. TP = {EN, LO} is the nodes' power, low condition means less than 10% of the capacity of the lithium battery. NNS = {CE, PA, SU} indicates the network status, such as central node, parent node and sub node. Regardless of the network status of the node, it is assigned a unique number. NWR = {0, 1} means the remaining number of warheads corresponding to TA. NWS = {N, I} means whether the node can work according to the feedback of each module. DDC = {0, 1} means whether the target is within the detection distance. ADC = {0, 1} means whether the target is within the attack distance. In the current situation, the detection distance is longer than the attack distance.

3.3 Hidden Variables

The hidden variables, which are the intermediate layer of logical reasoning and constructed according to the potential logical relationship of the observation variables, reflect targets and nodes situation information. The hidden variables of the attack decision model are shown in Table 2.

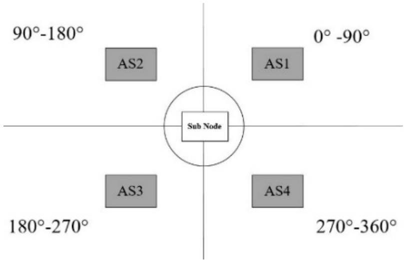

Figure 4. The division of TA.

Table 2. Hidden variables.

Variables	Meaning
TCS	Target comprehensive situation
NCS	Node comprehensive situation

TCS = TA*TS*TT means target comprehensive situation information. NCS= NP*NNS*NWR*NWS means node comprehensive situation information.

3.4 Decision Results

According to the decision result of the previous moment and the current time observation evidence, the current decision result is obtained. DMR = {WA1, WA2, WA3, WA3, DET, GUA}, the warhead used by the node attack is configured according to the target angle. The result is shown in Table 3.

Table 3. Decision result.

Variables	Meaning	Result
DMR	Warhead 1 attacks	WA1
	Warhead 2 attacks	WA2
	Warhead 3 attacks	WA3
	Warhead 4 attacks	WA4
	Keep detecting	DET
	Keep guarding	GUA

4 REASONING ALGORITHM

The DAG is used to represent the dependencies and independent relationships between variables, and the conditional probability table quantitatively describes the dependencies between nodes. The graphical structure qualitatively represents the relationship between the various variables (Wang Qingjiang, Peng Jun, Zeng Ruwei, Xu Xuewen, Ni Baohang and Shan Xin, 2014). It mainly studies the filtering in the dynamic Bayesian network reasoning task, which is to infer the posterior probability of the current moment based on the decision result of the previous moment and the evidence of the current moment. Since the current information propagation direction is forward broadcast, the improved reasoning algorithm can improve the reasoning problem under the condition of conclusive evidence and the reasoning problem under the condition of multiple types of evidence.

4.1 Bayes' Rule

Bayes' rule is the basis of DBN theory. Suppose that the probability of occurrence of random event x and random event y is P(x) and P(y). The probability of event x conditioned knowing event y is defined as

$$P(x|y) = \frac{P(y|x)P(x)}{P(y)} \tag{1}$$

4.2 Algorithm Description

In the improved reasoning algorithm, there are t – 1 and t time moments, t – 1 time moment represents past time and t time moment represents current. There are one root node, nine observation nodes and two hidden nodes in each time slice. The structure of the DBN for nodes attack decision is shown in Figure 5.

DMR_t is the value of the root node at time t, w is a collection of observed variables, η is the normalization factor, $P(DMR_t|DMR_{t-1})$ is the probability of state transition, $P(DMR_{t-1}|w_{1:t-1})$ is the reasoning result at time t – 1. So, the reasoning equation for the root node at time t is

$$P(DMR_t|w_{1:t}) = \eta P(w_t|DMR_t) \left[\sum_{DMR_{t-1}} P(DMR_t|DMR_{t-1})P(DMR_{t-1}|w_{1:t-1})\right] \tag{2}$$

Based on the conditional independence and chain passing rule, the root node at time t under the condition of the observed variable is

$$P(DMR_t|w_t) = P(DMR_t|TA_t)P(DMR_t|TS_t)P(DMR_t|TT_t) P(DMR_t|NP_t)\, P(DMR_t|NNS_t)P(DMR_t|NWS_t)' P(DMR_t|NP_t)\, P(DMR_t|NNS_t)P(DMR_t|NWS_t) \tag{3}$$

A link with a hidden variable can derive the conditional probability from the same principle. Take $P(DMR_t|TA_t)$ as an example

$$P(DMR_t|TA_t) = \sum_{TCS} P(DMR_t|TCS_t)P(TCS_t|TA_t) \qquad (4)$$

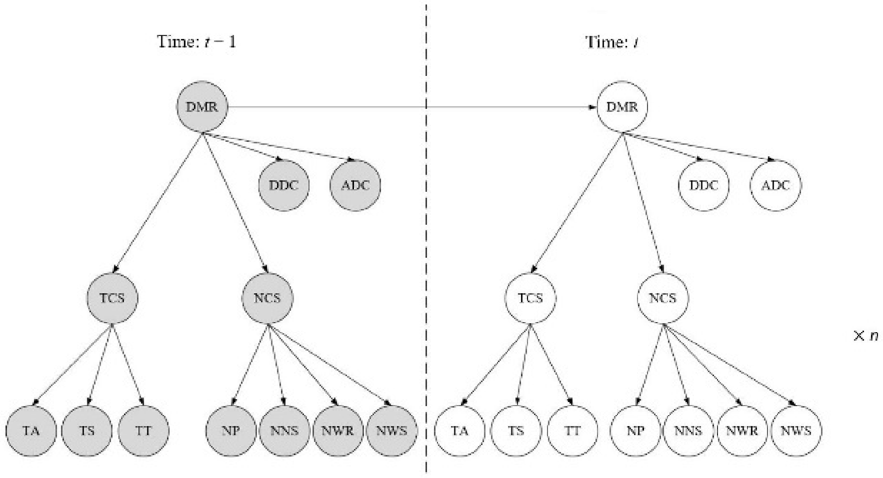

Figure 5. The structure of DBN for attack decision.

The prior probability and state transition probability need to be given in advance when calculating. Recursive calculation according to DBN reasoning method, the equation is

$$P(DMR_t|w_{1:t}) = P(w_t|DMR_t) \frac{\sum_{DMR_{t-1}} P(DMR_t|DMR_{t-1})P(DMR_{t-1}|w_{1:t-1})}{P(w_{1:t})} \qquad (5)$$

5 EXPERIMENT

5.1 System Test

Using the terminal software as the carrier to predict the effectiveness of the algorithm, open the software and load the wild mountain map. The single-machine test mode is selected to generate eight nodes including one central node and one parent node, and four ground targets which are the same type of tank. The nodes are networked according to the actual networking process. After the networking, the nodes enter the guarding state. When the targets appear, the algorithm module starts operation. Two of the targets enter the attack area, then the software calculates that the Node 6 and Node 7 are attacking. The result is WA3 of Sub Node 6 and WA1 of Sub Node 7. The running result is shown in Figure 5.

5.2 Semi-physical Simulation Experiment

In order to better test the performance of the algorithm, an outdoor semi-physical simulation experiment combining hardware and software is performed. The scene of outdoor semi-physical experiment is shown in Figure 7. Six wireless intelligent nodes in good working condition communicate with the terminal software after setting up. When the networking process is completed, one central node, one parent node, and four child nodes are displayed. Two ground targets' information are preset before the experiment.

Figure 6. Running result of system test.

Figure 7. The scene of outdoor semi-physical experiment.

When the two targets appear, the algorithm module starts running, one target is not in the attack range, and the other target assigns Node 6 to attack. The result is WA3 of Node 6. The running result is shown in Figure 8. The DBN inference method has dynamic adaptability. During the experiment, changing the node position, changing the node state and inputting new target information, the operation result will be changed accordingly. For example, when changing the node's battery power to low condition, this node will be given the priority to attack.

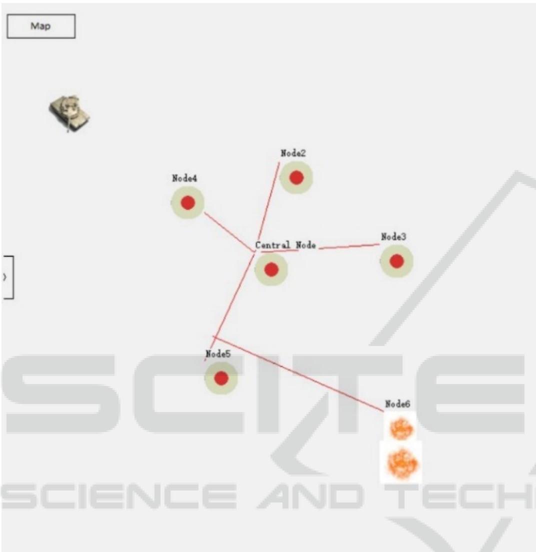

Figure 8. The running result of semi-physical experiment.

6 CONCLUSIONS

A multi-objective and multi-attribute attack decision model under uncertain conditions based on DBN is designed. According to tasks in wild, DBN reasoning method is used in the simulation system, which contains software and hardware. In the simulation test and the semi-physical simulation experiment, the DBN reasoning method is verified. The experiment shows that the method is practical and can provide decision support for researchers or commanders.

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