Research on Synergetic Evolution of Weapon Equipment System

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Abstract—**The non-linear cooperative interaction between various types of weapons and equipment in the weaponry system is the root cause of combat capability. In the process of system evolution, all kinds of weapons and equipment in the system will spontaneously adjust their own state and evaluate the rules of other weapons and equipment according to the evolutionary needs of the system. Therefore, this paper proposes a cellular automaton model which improved by differential evolution algorithm to study and analyze the internal synergy mechanism in the process of weapon capability generation. Finally, analyze and studie the specific examples to verify the feasibility of the model.**

Keywords—synergy; weapon equipment system; combat capability; DE-CA model

The cellular automaton is a dynamic system which is discrete in time, space, time, and simulates the complex relationship of the weaponry system by describing the local interaction between each discrete cell, which makes it possible to accomplish the task of simulating the complex behavior of the build system. However, when the cellular automata is used to simulate the complex system, it is not accurate enough to describe the autonomous individual units in the equipment system and their relationship. Therefore, the cellular automaton model cannot describe the system synergy comprehensively [1].

The differential evolution algorithm is an adaptive algorithm that guides the search for optimal solutions through mutual competitive cooperation among individuals in the population. This paper uses the difference algorithm to optimize the cellular automata, which abstracts the individual population into cell units, and then It is used to describe the synergy mechanism within the weaponry system [2].

By analyzing the specific examples, the synergistic relationship between the various components in the system is described from the microscopic point of view to determine whether the overall system approaches the macroscopic coordinated stability state, and the feasibility of the model in the system evolution research is verified.

I. The Overview Of The Related Theories

A. The Overview of Differential Evolution Algorithms

The differential evolution algorithm was proposed by Rainer Storn and Kenneth Price. It is a random parallel heuristic and adaptive global optimization genetic algorithm [3]. It guides the search process of the algorithm by analyzing the mutual cooperation and competing relationship among the individuals in the population. Therefore, the differential evolution algorithm is more suitable for the research of nonlinear, synergistic and adaptive problems in complex systems.

B. The Overview of Cellular Automata

The cellular automaton is a mathematical model proposed by von Neumann. It is used to recognize the complex phenomena in nature, time, space and state. As a kind of disserting dynamic model for simulating the complex systems, CA uses a "bottom-up" modeling method to describe the local interaction between each discrete cell to simulate the complex relationship of the whole system [4].

And CA has complete computing power and "explicit" computing power, so that it can simulate the complex behavior of the built system by virtue of its relatively powerful computing power and spatial-temporal discrete features [5].

C. The Overview of Coordination of Weapons and Equipment Systems

The synergy of the weaponry system describes a complex system of multiple weapon units which is nonlinearly formed in a certain environment and formed a non-linear organization in autonomous organization, which interacts with each other in spatial, temporal and functional interactions [6].

This kind of correlation effect makes each weapon and equipment achieve the synergy of the overall combat capability of the weapon equipment system through mutual coordination.

Based on the synergistic analysis of the evolution in the weapon equipment system, it describes that two or more components inside the equipment system are dynamically adjusted to their steady state by being driven by a common target. The weapon-based evolution model based on synergy has the characteristics of integrity, self-organization, relevance and dynamic behavior.

II. Collaborative DE-CA System Evolution Model

The cellular automaton is consisted of four parts: the cell space, the cell state, the cell neighbor and the evolution rule. The mathematical expression is as follows [7]:

$$A = (L, d, S, N, f)$$

Where A represents a cellular automaton; L represents the cell space; d represents the dimension of the cell space L; S represents the state set of the cell, which is a discrete and finite set of states; N represents the set of cells in all neighborhoods of the cell, consisting of space vectors of n th different cell states, which can be expressed as:

$$N=\left(s_1,s_2...s_n\right),s_i\in S\ \&\ i=1,2...n$$

f represents the mapping rule of $S^n \longrightarrow S^{n+1}$; As shown in FIG.1 below, the structural composition of the cellular automaton system is described.

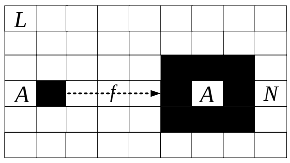

FIGURE I. SCHEMATIC DIAGRAM OF THE CELLULAR AUTOMATON

According to the evolutionary requirements of the system, the cellular automaton model is improved as follows: the cell state is extended from the discrete space to the continuous space, and the cell unit and its neighbors are optimized and updated according to the differential evolution algorithm, then the collaborative DE-CA evolution model is established as follows:

$$A^{+}=\left(L,S_{+},N^{g},f,\theta\right)$$

Where L denotes a continuous cell space; S_+ denotes a state set of cells in a continuous space, N^g denotes a cell set in all neighborhoods of the coordinated cell A^+, f is a mapping rule, and θ is a cell phase angle.

A. Cell and Cell State

The cell is the basic component of the cellular automaton model [7]. In the process of generating the combat capability of the weaponry system, this paper abstracts the weapon equipment packages to generate cooperative behaviors self-organized and it can evolve together to achieve the same function as the cell unit in the cooperative evolution model of the weapon equipment system.

The state value of the cell unit is quantized from the original data, and the original data after normalization is more suitable for the processing requirements of the evaluation system simulation calculation [8]. In this paper, the mean value method is used to quantify the data. It can not only meet the basic requirements of the evaluation system, but also ensure that the original data features are not lost after data processing. The specific operation of data quantization is shown as: $x=\frac{x_{original}}{\overline{x}}$.

According to the model requirements, the cell state is defined as the weapon combat capability, and the value range is set according to the actual demand: $s\in[0,10]$.

B. The Cell Space

In theory, the cell space is the Euclidean space of arbitrary dimensions, but at present, the spatial categories of the cellular automata studied are mostly one-dimensional cell space and two-dimensional cell space [9].

Discrete cell states do not describe complex system behavior well, so the cell space is extended from the two-dimensional Euclidean space to the contiguous space, and this spatial phase change is recorded as θ, as shown in FIG.2 below.

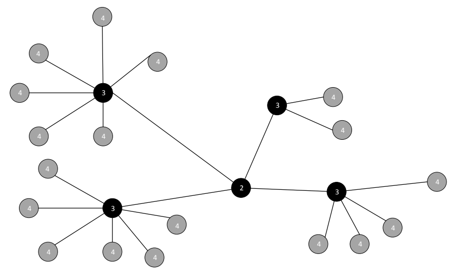

FIGURE II. CELLULAR SPACE IN A CONTINUOUS STATE

C. The Cell Neighbor

According to the preliminary setting of the system evolution model, the differential neighboring algorithm is used to optimize the cell neighbors, so that the cells have more synergistic characteristics.

The DE algorithm is mainly divided into four operations: population initialization, mutation, intersection, and selection.

It abstracts the individuals in the population as the reference vector, then randomly selects two reference vectors to make the difference and combines the obtained difference vector weights with the vector, and the obtained new vector is the mutation vector.

According to the degree of interference of the crossover factor in the original population, the experimental vector is generated by interleaving the mutated vector and the reference vector.

Finally, the experimental vector is selected according to the requirements of the system, and the vector more suitable for the original population is stored in the next generation population. The specific process is shown in FIG.3 below.

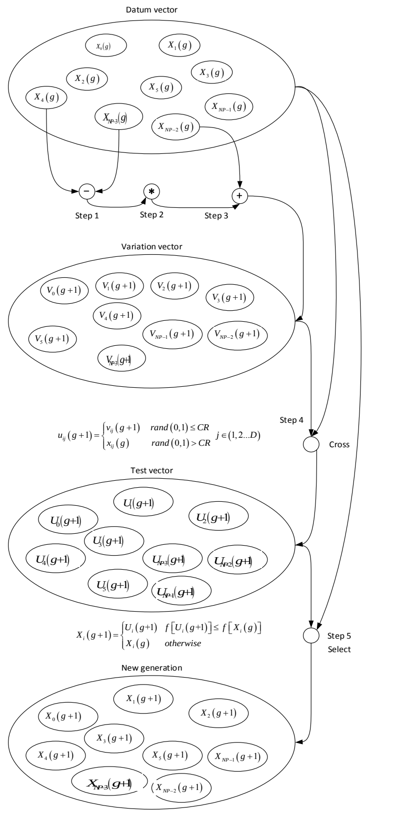

FIGURE III. FLOW CHART OF THE DE ALGORITHM

The population individuals in the differential evolution algorithm are mapped to the cell units in the cellular automaton, and the cell units are initialized, mutated, crossed, and selected [10]. The specific process is as shown in FIG. 4 below.

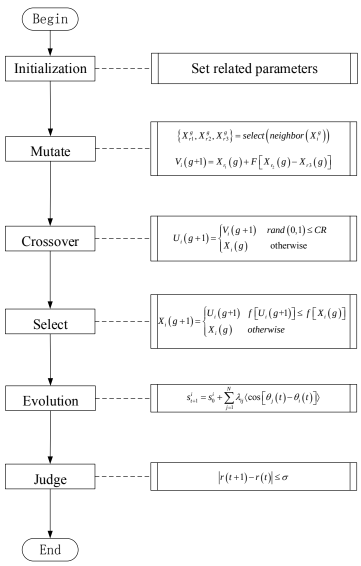

FIGURE IV. DE-CA ALGORITHM

D. The Evolutionary Rule

1). The cell phase change rule

Using the Kuramoto model to set θ 's function on time t [11]:

$$\frac{d\theta_i}{dt} = \omega_i + c_{ij}\sum_{j=1}^{N} a_{ij}\sin(\theta_i - \theta_j), i = 1, 2, \cdots, \mathrm{N}$$

2). The cell state mapping rules

$$s_{t+1}^{i} = s_0^{i} + \sum_{j=1}^{N} \lambda_{ij} \langle \cos\left[\theta_j(t) - \theta_i(t)\right]\rangle$$

E. The Evolutionary Termination Criteria

According to the model evolution requirements, the evolution termination criteria are selected. The specific formula is as follows:

$$r(t) = \frac{1}{N}\sqrt{\left(\sum_{k=1}^{N}\cos\theta_k(t)\right)^2 + \left(\sum_{k=1}^{N}\sin\theta_k(t)\right)^2}$$

Where $r(t) = 0$ indicates that there is no correlation between members in the entire system; $0 \le r(t) \le 1$ indicates the proportion of members participating in system coordination within the system; $r(t) = 1$ indicates that all members reach a coordinated state. If $\left|r(t+\Delta t) - r(\mathrm{t})\right| < \sigma, \quad \sigma \to 0^{+}$, the algorithm terminates.

III. MODEL VERIFICATIONS

In summary, a collaborative DE-CA weapon system evolution model is constructed. This section takes the Army's synthetic brigade as an example and uses its operational capability evaluation index system as a reference for calculation. By calculating the degree of the synergy between the cell unit and its neighbors, it is verified from a microscopic point whether the system is close to the steady state and the model. Effectiveness. details as follows:

A. Evaluation Index System for Combat Capability of Weapon Equipment System

Through the analysis of the composition of combat capability, the synthetic brigade based on the cooperative weaponry system combat capability index system structure is shown in FiG.5.

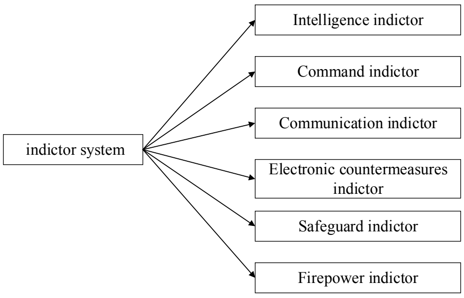

FIGURE V. WEAPON EQUIPMENT SYSTEM OPERATIONAL CAPABILITY EVALUATION INDEX SYSTEM

As shown in FiG.6, the combat capability of the synthetic brigade's weaponry system consists of six secondary indicators, each of which can continue to be hierarchically divided into four levels of indicators.

And each level 4 indicator is mapped to a cell unit. Taking the Intelligence investigation capability as an example, the mapping relationship between the 4-level indicator system and the cell unit is as shown in FIG. 7

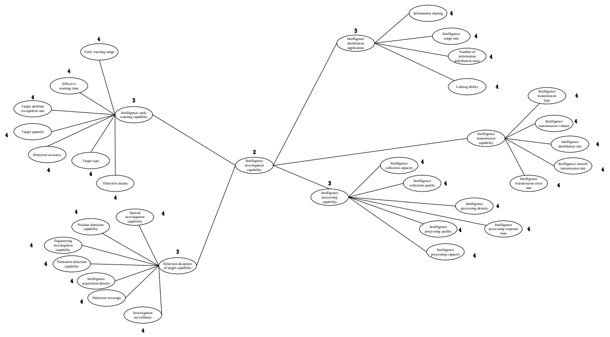

FIGURE VI. STRUCTURE OF THE OPERATIONAL CAPABILITY INDICATOR

B. Calculation of Synergy between Cell Units

Using the method of cooperative calculation of weapon equipment system with partial least squares method, this paper calculates the synergistic relationship between cell unit and its neighbors from the microscopic point of view, and then judges whether the macroscopic angle approaches the stable coordination state during the whole system evolution process.

Based on the above-mentioned synergy determination method, the operational capability values calculated by the DE-CA model are brought into the PLS algorithm [11], and the degree of synergy between the individual cell units is calculated by regression, and the correlation result is shown in FIG. 8.

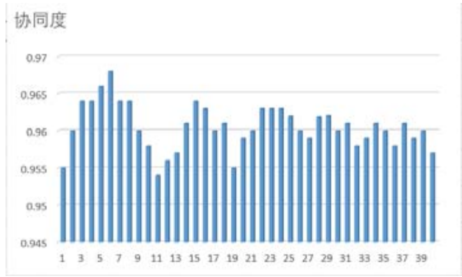

FIGURE VII. RESULTS

As shown in FIG. 7, it describes the degree of synergy between network coverage capability and network adaptability. Referring to the curve trend of FIG.7, it can be found that as the system evolves, the degree of synergy between the two is gradually stabilized. It is roughly 0.962. After expert evaluation and military research, the degree of synergy between network coverage capability and network adaptability is in line with the actual situation.

IV. CONCLUSIONS

In this paper, the differential evolution algorithm is applied to the cellular automaton model to optimize the cell unit, and the modeling process of the DE-CA model is introduced in detail. Finally, the degree of synergy between the individual cells is calculated to describe from the microscopic perspective whether the whole is in a coordinated state.

However, in the dynamic process of studying the evolution simulation of the weapon-based system based on synergy, how to accurately describe the self-adjustment process of the cell unit and the complex behavior of its neighbor's action rules requires further research.

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