ON PRIORITIZING, TARGET SELECTION AND SYNCHRONIZATION IN MULTITARGET SWARMING SIMULATORS*

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Abstract

The research of swarming tactics is underway at Union University School of Computing and at Military Technical Institute in Belgrade, Serbia. The basic simulator algorithm, intended for simulation of an armed mobile platforms group swarming in territory defence counter one target/threat has been improved, so that now it can be used in multi-target swarming simulations. The basic simulation model, initial assumptions, improved algorithm of armed mobile platform group's multi-target swarming simulator and its data structures and control mechanisms for multi-target swarming software simulators have been presented in the paper. The advantage of the proposed approach is that a swarm, besides local self-organization, is able to accept higher level directives on targets priorities. Also, the presented mechanisms enable a swarm to dynamically change its participants' assignment on every target appearance or removal in simulation. Finally, the proposed concept of swarm synchronization helps to reduce the probability of swarming failure, due to unsynchronized swarmers' destruction one by one by self-defensive capable target.

Keywords - Multi-target swarming, simulation, prioritizing, target selection, synchronization.

1 INTRODUCTION

Swarm and derived concepts like *swarm intelligence* and *swarming* have quickly become words *à la mode*, due to their extensive use as an analogy or the basis of other uses of the terms, in various areas of science and technology, and recently in military applications too [1, 2, 3, 4].

The research of swarming, based on discrete events simulation, is underway at Union University School of Computing and at Military Technical Institute in Belgrade, Serbia [5].

Armed mobile platform (AMP) group swarming is a new armoured units' tactics, proposed in [6], where AMPs repeatedly attack an adversary from many different directions, and then regroup. The swarming tactics is applied by manoeuvrable units much smaller than threat/target, but their use is far more efficient, so in their actions as a whole, they can often defeat many times superior adversary [1, 2].

Computer simulations of such swarming systems impose important issues, especially in multi-target cases: multiple target representation, introduction, removal, prioritizing and selection, as well as APM synchronization.

In this paper, the basic simulation model has been shortly presented, followed by initial assumptions, improved algorithm of armed mobile platform group's multi-target swarming simulator, data structures and control mechanisms for multi-target swarming software simulators.

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2 SIMULATION MODEL

The simulated system [7, 8, 9, 10, 11] consists of a group of N armed mobile platforms AMP-*i* and M targets T-*j*. The model is the discrete events one, with activities represented by time delays. Swarming is taking place in a territory represented by 2-D rectangle coordinate system (Fig. 1).

The AMPs get from C^4I system the information on targets and other AMPs, and report their own current positions in time intervals Δt. According to that information, AMPs direct themselves toward targets, aiming to reach the position for successful swarming.

In order that individual swarming participating AMP-*i* could act upon target T-*j*, the following conditions must be fulfilled:

a. AMP-*i* should have weapon W-*i*, compatible with target T-*j*.

b. Distance from AMP-*i* to T-*j* must be within W-*i* range, R_{w-i}:

$$D_{ij} = \sqrt{(y_j(t) - y_i(t))^2 + (x_j(t) - x_i(t))^2} \le R_{W-i} \tag{1}$$

The a. and b. conditions must be satisfied by enough AMPs, so that their cumulative effect, CE_j should be equal or greater than the critical threshold, CCE_j, specific to target T-*j*:

$$CE_j = \sum_{i=1}^{N} A_{ij} \cdot C_{ij} \cdot E_{ij} \ge CCE_j \tag{2}$$

Where: A_{ij} is assignment coefficient (0/1) of AMP-*i* to T-*j*; C_{ij} is W-*i* compatibility coefficient with T-*j* (0/1); E_{ij} is effect of W-*i* on T-*j*.

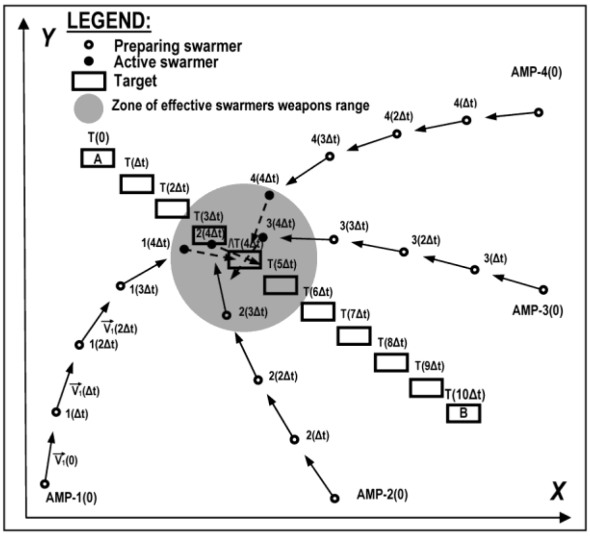

Fig.1 Swarming: group of 4 AMPs against 1 target

The basic algorithm of AMP group's swarming simulator has been described in [7]. It deals with the case when a group of armed mobile platforms defending the territory applies swarming tactics against one target/threat unit.

3 MULTITARGET SWARMING

The basic algorithm of the AMP group's swarming simulator has the limitation that it deals with appearance of one sole target/threat. That is not a problem when relatively small groups of AMPs are considered, having in mind that such groups are most frequently engaged in combat activities against only one serious threat.

However, an armoured battalion, as a basic tactical unit considered in the research, has opportunities to apply simultaneous swarming against 2, 3 and even more different targets/threats.

Besides quantitative enlargement of simulators, that also imposes some new issues, related to target selection, priorities, AMP's compatibility with targets/threats, and AMP group's synchronization and other self-organizing capabilities in such situations. Therefore it was necessary to improve previously developed algorithm, so that the AMP group's swarming against several threat/target units simultaneously present in defended territory could be simulated.

An improved algorithm, intended for multi-target swarming simulator, is presented in Fig.2. It is proposed having in mind the following initial assumptions:

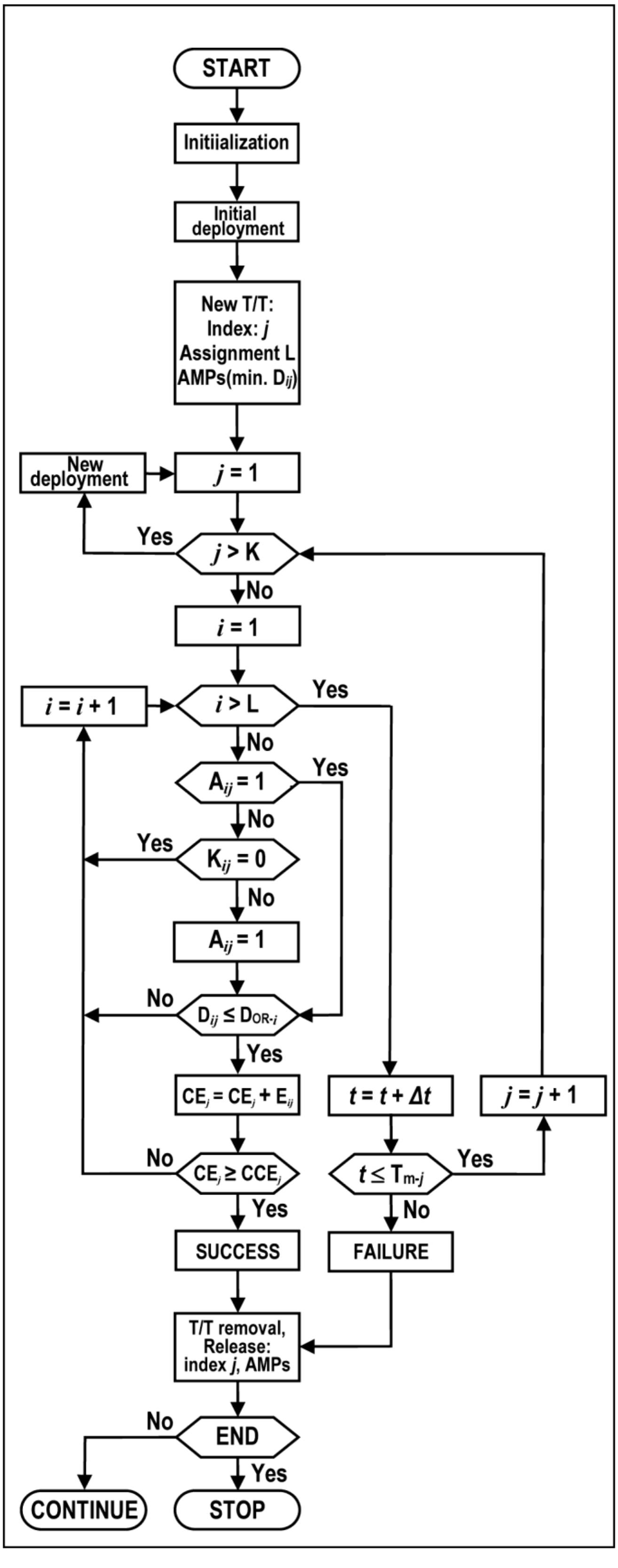

Fig.2 A multitarget swarming simulator algorithm

Threats/targets appear in the swarming territory independently, in arbitrary spatial and temporal disposition.

- Every new threat/target is on its own mission, characterized by its own law of motion and point in space which it has to reach by such motion.
- Every threat/target is defined by its critical threshold of cumulative effect of several armed mobile platforms which perform swarming against it.
- AMP group engages its armed mobile platforms assuming that all target/threats appearing in the defended territory are of equal importance, and differ only in sequence of arrival, i.e. deals with them on the FCFS (first come-first served) basis, unless some other priority policy is introduced.
- Priorities can be introduced, providing that higher control level (above particular swarming) has insight in total situation in the defended territory and is capable of issuing appropriate directives by means of the C^4ISAR system.
- AMP group engages sufficient number of AMPs against every present target/threat, providing potentially successful swarming. AMPs are assigned against targets/threats by assigned priorities (if there are any), or else by least distance criterion. The remaining AMPs against other target/threats, if there are some in the defended territory.
- After successful swarming, target/threat is removed from simulation; the AMPs engaged in swarming against that target/threat are released, in order that all those resources could be assigned to new target/threats entering the simulation.

To improve the basic swarming simulator algorithm [7] and make it suitable for multi-target swarming, it has been necessary to introduce additional data structures and mechanisms in the existing model. Those are: 3-D distance and assignment order matrix DAO(*i*,*j*,*k*) with its 2-D sub-matrices for distance D(*i*,*j*) and assignment order AO(*i*,*j*), and control mechanisms for target prioritizing, selection, armed mobile platforms assignments and synchronization.

4 CONTROL MECHANISMS FOR MULTITARGET SWARMING SIMULATORS

3-D DAO (*i*,*j*,*k*) matrix [8] is a central data structure that all control mechanisms rely on. The roles of its indices are:

- Index *i*: AMP-*i* to target T-*j* assignment order determination;
- Index *j*: T-*j* current index and priority; the less *j*, the higher T-*j* priority, i.e. the sooner it is considered for AMPs assignments;
- Index *k*: definition of 3-D matrix DAO(*i*,*j*,*k*) 2-D sub matrices:
    a. *k* = 1 defines 2-D distance sub matrix D(*i*,*j*), which holds current distances from AMP-*i* to T-*j*;
    b. *k* = 2 defines 2-D assignment order sub matrix AO (*i*,*j*), which holds identification numbers of AMP-*i* that distances D (*i*,*j*) are related to.

The matrix is generated in detection time of the first target T-1, when it is reduced to single-columned; in subsequent intervals Δ*t*, changes of the matrix structure occur, and index *j* maximal value depends on appearance and/or removal of targets in simulation:

a. If a new target occurs, it gets index *j* value equal to the greatest *j* so far incremented by 1, and a new column is added to the matrix.
b. If an existing target is removed, all AMPs assigned to it are released, content of all columns with indices *j* greater than that target's index are shifted by one place to the left and the last column is removed.

4.1 Target prioritizing mechanism

The target priority issue [8] is resolved by means of T-*j* current index *j*; the less *j*, the higher T-*j* priority:

a. If all targets are of the same priority, assigning of AMPs is according to the order of their appearance in simulation. That is achieved by giving new targets ever increasing values of index *j*, and new columns in the matrix further away from the first column belonging to T-1.

b. If a new target should have priority level higher than some of the existing targets, it pre-empts that target's current index j and its column, and the pre-empted target's column, as well as columns of all other targets with less priorities shift one place to the right.

4.2 Target selection mechanism

The target selection mechanism [8] is activated at the beginning of every interval Δt**.** If, in the meantime, some new targets appear in simulation, or some of the existing ones disappear, the appropriate changes in the DAO (*i*,*j*,*k*) matrix structure are carried out, and new distances of all targets T-*j* from all AMP-*i* are entered.

Then, the sorting of distances in ascending order is executed for all targets T-*j*. The data displacements in sub matrix D(*i*,*j*,1) necessary for sorting are executed simultaneously with appropriate displacements of corresponding AMP-*i* identification numbers in sub matrix AO(*i*,*j*,2).

Finally, 2-D assignment matrix A (*i*,*j*) is generated, holding identification numbers of platforms AMP-*i*, assigned to targets T-*j*. For every T-*j*, the A (*i*,*j*) matrix is filled in order, up to the number of AMPs whose cumulative effect is sufficient to insure successful swarming against T-*j*. Then, the assignment mechanism passes to the next target T-(*j*+1), except that it can not assign AMPs that are already assigned to T-*j*. Filling of A (*i*,*j*) stops when all available AMPs are assigned to existing targets. That assignment is valid until the possible changes in the next Δt.

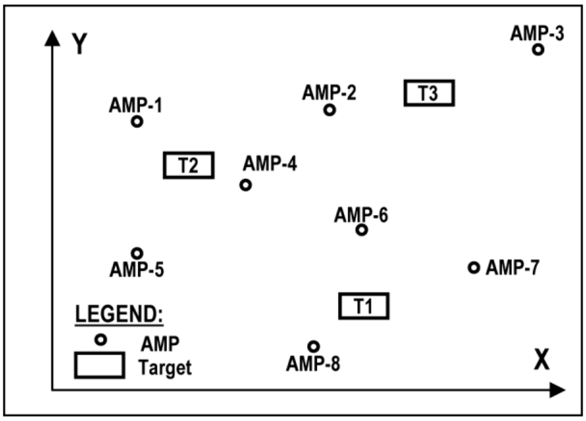

Fig. 3 Multitarget swarming: an example

The operation of aforementioned mechanisms has been illustrated in [8], by means of a simple example system (Fig.3), consisting of 8 AMP-*i*, *i* = 1 - 8, and 3 targets T-*j*, *j* = 1-3. Index *j* reflects the priority of target – the less *j*, the more important T-*j* is. To achieve successful swarming, it is necessary to engage 4 AMPs for T-1, 3 AMPs for T-2, and 2 AMPs for T-3.

a. Before sorting D_{ij} distances

Distance submatrix

i \ j	1	2	3
1	D_{11}	D_{12}	D_{13}
2	D_{21}	D_{22}	D_{23}
3	D_{31}	D_{32}	D_{33}
4	D_{41}	D_{42}	D_{43}
5	D_{51}	D_{52}	D_{53}
6	D_{61}	D_{62}	D_{63}
7	D_{71}	D_{72}	D_{73}
8	D_{81}	D_{82}	D_{83}

Assignment order submatrix

i \ j	1	2	3
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8

Assignment matrix

i \ j	1	2	3
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	-	-	-
7	-	-	-
8	-	-	-

b. After sorting D_{ij} distances

Distance submatrix

i \ j	1	2	3
1	D_{81}	D_{42}	D_{23}
2	D_{61}	D_{12}	D_{33}
3	D_{71}	D_{52}	D_{63}
4	D_{41}	D_{22}	D_{73}
5	D_{21}	D_{62}	D_{43}
6	D_{51}	D_{82}	D_{83}
7	D_{11}	D_{72}	D_{13}
8	D_{31}	D_{32}	D_{53}

Assignment order submatrix

i \ j	1	2	3
1	⑧	4	2
2	⑥	①	③
3	⑦	⑤	6
4	④	②	7
5	2	6	4
6	5	8	8
7	1	7	1
8	3	3	5

Assignment matrix

i \ j	1	2	3
1	8	1	3
2	6	5	-
3	7	2	-
4	4	-	-
5	-	-	-
6	-	-	-
7	-	-	-
8	-	-	-

Fig.4 A multitarget swarming simulator data structures

Based on the situation in Fig.3, the distances of all platforms AMP-*i* from all targets T-*j* are calculated and entered in the matrix DAO (*i*,*j*,*k*).

Distances in the distance sub matrix (Fig.4a) are unsorted, given in ascending order of AMP identification numbers. In assignment order sub matrix AO (*i*,*j*,2), whose elements are AMPs identification numbers, that order is the same for every target T-*j*. The assignment matrix A (*i*,*j*) content in this phase is irrelevant, being caught from previous Δt.

Then, the distances sorting of every AMP-*i* from every target T-*j* is executed. In the distance sub matrix, the distances are now in ascending order for every existing target T-*j* (Fig.4b). The assignment order sub matrix is formed according to the distances ascending order.

In Fig. 4b one can also see the possible assignment of AMPs to every single existing target, according to its priority in the system. The first 4 AMPs from the column *j* =1 (AMP-8, 6, 7 and 4) are assigned to T-1. AMP-4 cannot be assigned to T-2, being already assigned to T-1 as the higher priority target; so

AMP-1, 5 and 2 are assigned to T-2. The remaining AMP-3 is the only one that is assigned to T-3.

Following that assignment order, the assignment matrix A (*i*,*j*) is updated (Fig.4b), and AMPs accordingly direct themselves to their targets (Fig.5). Such assignment in multi-target swarming will be valid during the current interval Δt. The AMP group has enough resources to apply successful swarming against targets T-1 and T-2, but requirement of T-3 at the time being overcomes available capacity of the group.

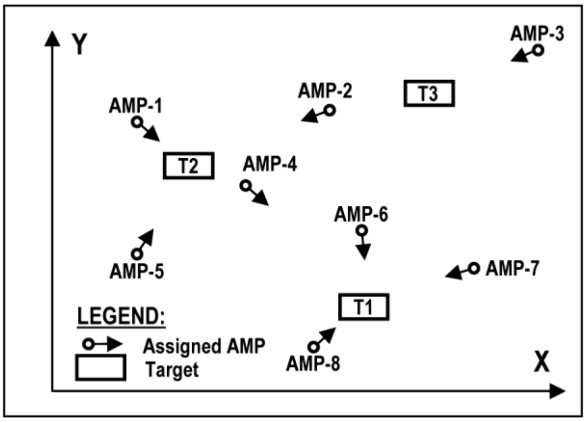

Fig. 5 AMPs assigned and directed to targets

At the end of current interval Δ*t*, changes are possible in structure of the DAO (*i*,*j*,*k*) matrix, its sub matrices D and AO, and in the resulting assignment matrix A (*i*,*j*).

4.3 Synchronization

The synchronization problem arises if AMPs applying swarming against self defence capable target/threat don't reach the distance from it within the range of their main weapons in approximately same time and in a number large enough to achieve critical threshold of their cumulative effect. In that case there is a probability of swarming failure, because target/threat could destroy AMPs one by one, as they appear within the range of its own weapons.

To solve this problem, we have proposed in [9] the introduction of synchronization zone (SZ), circular ring around target/threat (Fig.6), defined by the expression:

$$SZ = R_{WT-j}(1 \pm q) \tag{3}$$

Where: $R_{WT\text{-}j}$ is the effective range of T-*j* own weapon, and $0 < q < 1$.

Such a mechanism enables, while there are not enough AMPs for successful swarming, that:

- AMPs far from target/threat continue (AMP-1, 2, 3, 4 and 6 in Fig.6) to approach it by the shortest possible way;
- AMPs in the *SZ* (AMP-5 and 7 in Fig.6), are moving in parallel with target/threat at a relatively safe distance, ready to move towards target/threat again, when enough AMPs gather for successful swarming cumulative effect;
- AMPs near target/threat (AMP-8 in Fig.6) are moving away from it towards *SZ*, in order to avoid individual destruction and swarming failure.

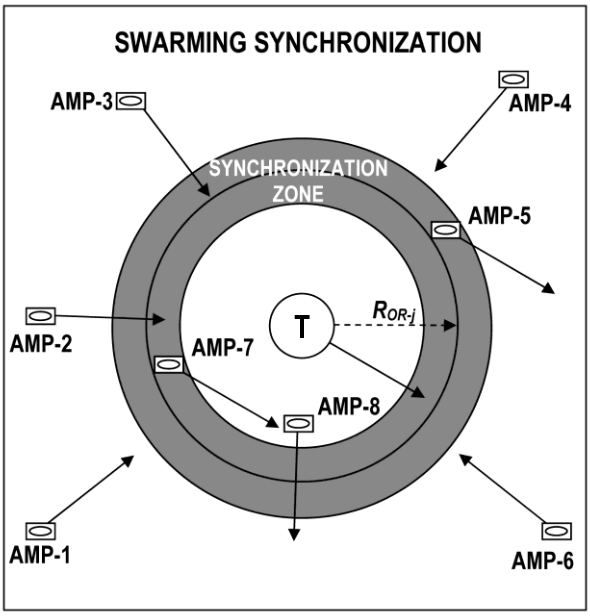

Fig. 6 Armed mobile platforms swarming synchronization

5 CONCLUSION

Computer simulations of swarming systems impose some important issues, especially in multi-target cases: multiple target representation, introduction, removal, prioritizing and selection, as well as swarmers' synchronization. Some of concepts intended to address these issues have been presented in the paper.

The prioritizing and selection mechanisms for multi-target swarming simulators rely on 3-D dynamically structure changing matrix, depending on appearance or removal of targets in simulation. They are activated at the beginning of each C^4I system reporting interval Δt and deliver an assignment matrix, containing the information on assignments of armed mobile platforms to selected targets. The assignment is valid for the current interval Δt, and is recalculated for each of the subsequent ones.

The synchronization problem arises when swarmers don't reach at approximately same time the critical distance from a self defence capable target in a number which satisfies successful swarming condition. In such cases, swarming would probably fail, because the target could destroy swarmers one by one. The proposed mechanism, particularly its synchronization zone, enables swarmers to keep on moving, and protects them from destruction while they gather until their number makes the ongoing swarming successful.

The advantages of the proposed control mechanisms are:

- They enable swarm reorganization at every interval Δt, according to new information from C^4I system;
- Simple target prioritizing, by means of target current index *j*;

- Simple introduction of higher command level directives, relevant for multi-target swarming organization.

The presented mechanisms are intended for armoured units' multi-target swarming simulators, but can also be used in other swarming systems applications, both military and civilian.

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