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SIMULATION MODEL OF TERRITORY CELL DEFENCE AGAINST HELICOPTER AS A HYBRID THREAT

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Abstract: *A discrete events simulation model of a system consisting of several self-propelled air-defence missile-gun systems which apply swarming tactics defending three-dimensional territory cell against helicopter as a hybrid threat is presented in this paper. The system consists of three-dimensional territory cell as a combat space, helicopter as a hybrid threat, several self-propelled missile-gun defending systems, and the command-information system which enables control of such a defence. Territory cell is a space defined by surface coordinates and maximal height of defenders' combat actions against targets in the air. Helicopter is defined as a hybrid threat, breaking through three-dimensional territory cell towards its target, in order to execute unconventional combat actions against its target. Its success is defined by its arrival at predefined distance of its target. One or several self-propelled missile-gun defending systems apply swarming tactics to arrive in positions suitable for their missile and artillery weapons' fire actions counter helicopter. Defenders' command information system enables operation in four different modes: stand-alone, within a battery, within a command post, and with a command post and early warning radar. The imperfections of such a system are also considered and represented by probability of occasional lacks of position information of hybrid threat and other moving parts of the simulated system. The necessary definitions have been given, as well as starting assumptions, the simulated system description, the simulation model basics and the simulator algorithm.*

Keywords: *modelling; hybrid warfare; territory cell defence; helicopter; self-propelled missile-gun system.*

1. INTRODUCTION

We are living in dangerous times, burdened by various conflicts, ranging from local and regional ones, up to general inter-civilization wars, in which even those countries and their armed forces that tend to stay neutral, are subjects of huge pressures, different forms of hybrid warfare in particular.

Hybrid warfare can be defined as "conflict involving a combination of conventional military forces and irregulars (guerrillas, insurgents, and terrorists), which could include both state and non-state actors, aimed at achieving a common political purpose" [1].

As conflicts in the future will have elements of both conventional and irregular activities, a hybrid strategy will be required to combat the hybrid threat [2].

In this paper, two opponent arms are considered as being used by participants in hybrid warfare:

- Armed attack helicopter, as a hybrid threat (HHT), which is a suitable platform [3] for unconventional warfare actions (missile attacks, and/or diversion team transport);
- Self-propelled missile-gun systems (SPMGS), which defend helicopter's target (TARGET), situated in the middle of 3-dimensional territory cell (TC) around it.

For small countries, and their armed forces, tending to be neutral, it is worth researching possible issues of such hybrid conflicts, because they are likely to occur even outside a conventional war, officially declared between states. Having in mind recent procurements of general-purpose armed attack helicopters and state of the art in neighbour states' armed forces, it isn't impossible that hybrid threats of that kind could occur in foreseeable future. In addition, there is not much published practical experience of SPMGS use in such hybrid conflicts.

In order to get more knowledge and develop suitable tactical procedures for using such weapons in hybrid warfare, a research is proposed using technique of discrete events simulation. This technique proved itself worthy in authors' earlier research, when several simulators have been developed, mainly in the area of artillery and mechanized units at the battalion level swarming tactics ([4], [5], [6], [7]) application in defence counter passive and active threats ([8], [9], [10]). In ([11], [12]), artillery and missile were units introduced in the research, i.e. self-propelled missile systems, which defend a 2-dimensional ground territory cell (TC) counter an active threat, using swarming tactics combined with a synchronized multi-missile attack.

The goal of this paper is to present the approach to simulation modelling of 3-dimensional territory cell defence against a helicopter as a hybrid threat.

In Section 2, the system to be simulated has been presented, by description of its components: 3-dimensional territory cell, helicopter as hybrid threat, self-propelled missile-gun systems as defenders, and command-information system.

In Section 3, simulation model algorithm has been presented, as well as the simulated system performance measure, and possibilities of the simulator realization.

It is expected that such simulators, once realized, could be useful cost effective tools for preliminary research of new tactical procedures, needed for application in such future hybrid conflicts.

2. SIMULATED SYSTEM

The simulated system consists of: 3-dimensional territory cell (TC), helicopter as a hybrid threat (HHT), self-propelled-missile-gun systems (SPMGS) as TC defenders, and command-information system (CIS).

2.1. Territory cell

Territory cell (TC), actually the battlefield, is a rectangle 3-dimensional space, with relative origin of coordinates in one of its base's corners, and characterized by maximal values of its coordinates (X_{max}, Y_{max}, $Z_{max}= A_{Mmax}$), where A_{Mmax} is the maximal altitude at what the defender's self-propelled missile-gun system (SPMGS) can launch missiles at a helicopter as a hybrid threat (HHT) in the air.

Within TC, a HTT's **target** (TARGET) is situated on the ground, presented by its coordinates T ($X_T=X_{max}/2$, $Y_T=Y_{max}/2$, Z_T).

2.2. Helicopter as a hybrid threat

In the beginning of the simulation, **helicopter as a hybrid threat** (HHT) is on random position, at any of the TC vertical sides; after that it directs itself towards its TARGET, according to its prescribed motion law and with its maximal possible velocity, V_{HHTmax}.

HHT can attack its TARGET by guided missiles, with maximum effective range $R_{MHHTmax}$, and is capable to transport diversion team of N_{dt} persons.

HHT mission is assumed to be successful, provided it manages to approach its TARGET at defined minimal distance $D_{HHT\text{-}TARGETmin}$, according to its mission type: missile attack to TARGET, or transport of a diversion team.

2.3. Self-propelled missile-gun systems

Self-propelled ground-to-air missile-gun systems (SPMGS) are randomly deployed in the beginning of the simulation, across the whole defended CT ground area.

SPMGS mission is to destroy HHT before it reaches defined minimal distance to TARGET, $D_{HHT\text{-}TARGETmin}$.

SPMGS is capable to launch missile on the move, in salvos consisting of 2 missiles launched simultaneously. The hit probability of HHT by one such salvo is:

$$p_s = 1-(1-p_m)^2 \qquad (1)$$

Where:

p_m: probability of HHT hit by 1 missile

SPMGS can launch the second salvo of 2 missiles after delay time of t_{2s}. If SPMGS fails to hit HHT in both first and second salvo, it abandons attempt to destroy HHT by means of missiles.

SPMGS is also capable to attack HHT by means of its automatic guns, with a hit probability of p_g. That is applied in cases when SPMGS is in such position that it can't hit HHT by missiles, due to its distance and/or height, or failure of both first and second missiles salvos.

SPMGSs apply an offensive-defensive tactics against HHT, in the following two phases:

- **Swarming**, during which they direct themselves towards HHT, in order to approach it at their missiles' or guns' possible attack zone (PAZ);
- **Attack** HHT with their missiles or guns, according to fulfilment of conditions required for each type of combat action.

PAZ for SPMGS missiles is defined by:

- Missile maximum/minimum range (R_{Mmax}, R_{Mmin});
- Missile maximum/minimum altitude (A_{Mmax}, A_{Mmin});
- Maximum/minimum elevation angle (α_{Emax}, α_{Emin}).

PAZ for SPMGS guns is defined by:
- Gun maximum/minimum range (R_{Gmax}, R_{Gmin});
- Gun maximum/minimum altitude (A_{Gmax}, A_{Gmin});

SPMGS can move by its maximum velocity $V_{SPMGSmax}$, and within its maximum mobility range $R_{SPMGSmax}$.

SPMGS can operate in one of the following modes:

- Stand-alone (SA);
- Within a battery (WB);
- Within a command post (WCP);
- With command post and external radar (WCPR).

One single SPMGS can operate in SA or WCPR mode. At least two SPMGSs can operate in WB, WCP or WCPR.

2.4. Command information system

Command-information system (CIS) provides to all SPMGS information of HHT current position, as well as the positions of every other SPMGS and other parts of the system of interest.

CIS is implemented on every SPMGS (sensors, computers and communication facilities) in all modes of operation, and supplies information in its basic intervals $\triangle t$. In addition, in WCPR mode, it can obtain information from external radar, in intervals $\triangle t_{ext}$.

In the earlier realised simulators in this research, CIS has been modelled as a perfect one, i.e. in every of its basic time interval $\triangle t$ it provided information on current positions of every moving part of the simulated system, the threat in the first place.

In [13], the notion of **CIS imperfection** has been introduced, presented by lack of expected information in some of its basic intervals $\triangle t$. The approach to CIS imperfection modelling is that its measure is the probability of CIS information absence (p_{fCIS}) in any interval $\triangle t$. In the simulator, p_{fCIS} is the input parameter, which has its chosen value during simulation experiment. The consequence of CIS imperfection is the uncertainty of active HHT real position, which affects the activity of SPMGSs, directing to HHT based on the unreliable information.

In previously realized simulators, both the threat and the TC defenders were situated and moving on the TC ground surface, so the concept of 2-dimensional CIS parallax has been introduced [13], defined as the difference between the threat real current position and its fake position, estimated from unreliable imperfect CIS information.

Having in mind that a helicopter as HHT is capable of flying in the whole TC altitude range (from TC ground surface to $\mathrm{A}_{\mathrm{Mmax}}$), it is necessary to introduce the new concept of **3-dimensional CIS parallax** (depicted in **Figure 1.**), and to use both 2-D and 3-D CIS parallax, according to HHT current position in simulation.

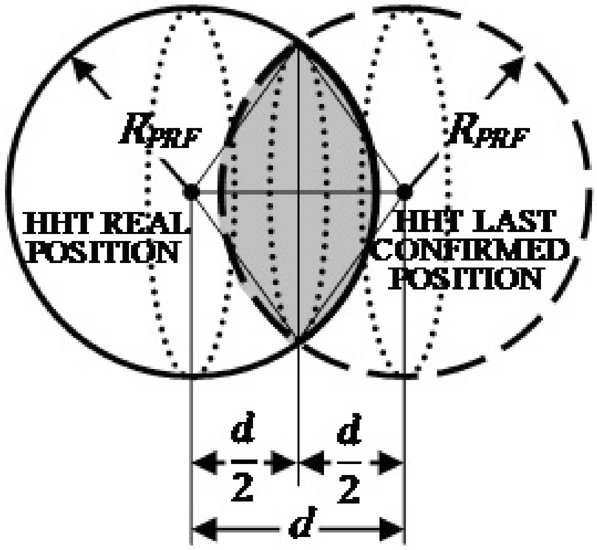

Figure 1. CIS 3-dimensional parallax

In cases of information absences in one or more interval $\triangle t$, SPMGSs are heading themselves towards the last confirmed HHT position, so the criteria for possible actions against HHT are accordingly updated and it is estimated whether the conditions for missiles launching or automatic gunfire are met.

In the simulation, as well as in the real world system, **CIS parallax** can appear (**Figure 1**), defined as the difference between real current HHT position and its fake position, which is estimated from unreliable imperfect CIS information. The CIS parallax measure is distance d between real and the last confirmed AT position:

$$d=\sqrt{(x_{HHT}-x_{cHHT})^2+(y_{HHT}-y_{cHHT})^2+(z_{HHT}-z_{cHHT})^2} \quad (2)$$

Where:

$(x_{HHT}, y_{HHT}, z_{HHT})$: HT real coordinates

$(x_{cHHT}, y_{cHHT}, z_{cHHT})$: HHT last confirmed coordinates

Imperfect CIS 3-D parallax could have two different effects to SPMGS CT defence mission:

- Within current simulation pass, it could happen that until HHT arrives to its TARGET, due to uncertain estimation of HHT position by imperfect CIS, the criteria for possible missile salvo launch (CMSL) and possible gunfire action (CGFA) were not fulfilled, so in that pass there will be no otherwise possible missile or gunfire attack at HHT;
- Due to imperfect CIS 3-D parallax, the false fulfilment of possible CMSL or CFGA criteria could happen, which results by launching of missile or gunfire attack at HHT that could be unsuccessful.

Both of these phenomena influence the success of the combined tactics of swarming and missile or gunfire attack, which results in increased number of failures in simulation. The first phenomenon happens during the whole simulation: as well as in the real world system, SPMGSs head towards HHT based on its current position (x_{HHT}, y_{HHT}, z_{HHT}), which is provided by CIS in every interval $\triangle t$. In cases this information fails in some of those intervals, SPMGSs are directed to the last confirmed HHT position (x_{cHHT}, y_{cHHT}, z_{cHHT}) and they will continue to do it that until the new information about HHT real position comes from CIS. As for HHT, it constantly moves towards its TARGET, no matter what SPMGSs do in the meantime.

The consequence is that in some simulation passes in the experiment it could happen that the launching or gunfire criterion is not fulfilled until the HHT mission completes, regardless the fact that it would happen if CIS was perfect and was timely providing the reliable HHT position information in every time interval $\triangle t$.

On the other hand, if at the moment of the launching or gunfire criteria fulfilment such decision is made based on uncertain HHT position due to CIS parallax, it could happen that the real proximity missile fuse zone, or possible gunfire zone around HTT are missed, due to imperfect CIS information.

The probability p_{MSL} that the decision of launching missile salvo by SPMGS is the right one, in the simulator is calculated as:

$$p_{MSL}=\frac{V_{ZMSL}}{\frac{4}{3}R_{PRF}^{3}\pi} \quad (3)$$

Where:

V_{ZMSL}: intersection volume of the real proximity missile fuse zone sphere, and the one got based on the fake HHT position (2 identical spherical caps of the height $h = R_{PRF} - d/2$);

R_{PRF}: missile proximity fuse action radius.

In **Figure 1** CIS 3-D parallax general case is presented, when both the real V_{ZMSL} and that one calculated based on the fake HHT position, due to CIS imperfection, are in air over TC. Depending on the real to fake HHT positions distance d, the probability p_{MSL} can be determined as:

For $d = 0$, $p_{MSL} = 1$

For $d \geq 2\,R_{PRF}$, $p_{MSL} = 0$

For $0 < d < 2\,R_{PRF}$, p_{MSL} is calculated as:

$$p_{MSL} = \frac{\left(R_{PRF} - \frac{d}{2}\right)^2 \left(2R_{PRF} + \frac{d}{2}\right)}{2R_{PRF}^2} \tag{4}$$

3. SIMULATION MODEL

The simulator algorithm is depicted in **Figure 2.**

INITIALIZATION of simulator comprises the experiment parameters entering, such as:

- Number of completed simulation passes in the experiment (SAMPLE);
- Territory cell characteristics;
- Number and characteristics of SPMGS;
- HHT characteristics;
- HHT to its TARGET motion law or itinerary;
- Criterion for missile salvo launch decision (CMSL);
- Criterion for gun fire action (CGFA);
- Counters starting values: SUCCESS=0, FAILURE=0

END OF EXPERIMENT condition is met when the count-down counter of completed number of simulation reached 0 (SAMPLE=0). If the condition is met, the simulation stops and the report of results of interest is generated. If it is not, the simulation continues.

INITIAL DEPLOYMENT comprises: starting positions of HHT and SPMGSs. At the beginning of the simulation passes, HHT in one of the TC vertical edges, and SPMGSs randomly situated on TC ground surface.

It is examined if the TC defence operates in WCPR mode. If it is in WCPR mode, it is examined whether HHT is detected by external radar. If HHT is detected, its position is passed to all SPMGSs. If it is not, it is examined whether HHT is detected by any SPMGS radar.

If HHT is detected neither by external radar, nor by any of SPGMS radars, the simulation clock is advanced by one of the command-information system's basic interval $\triangle t$. Then, it is examined whether the simulation clock value is still less than the time instant when HHT reaches its TARGET ($t < T_m$).

If $t < T_m$, HHT advances to its new position on its way to TARGET, and SPMGSs move towards HHT's last known position, depending on if they detected by means of the information provided by the external radar, or by some of their own radars. If they still have no such information, they don't move, until they get it, one way or the other.

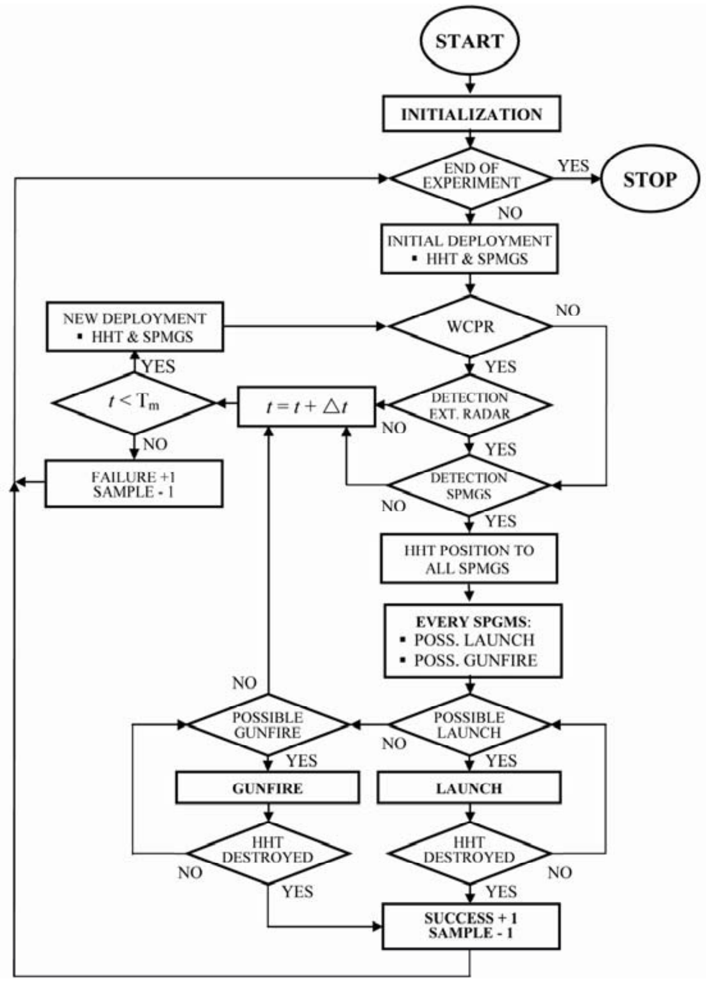

Figure 2. Simulation algorithm

After HHT and SPMGSs finished taking their NEW DEPLOYMENT, it is examined whether TC defence is in WCPR mode, and the simulation continues, as described.

If $t \ge T_m$, in actual simulation pass HHT is not destroyed before it completed its mission, the FAILURE counter is increased by 1 (FAILURE+1), the experiment termination counter is decreased by 1 (SAMPLE-1), and it is examined whether the experiment is over. If is over (SAMPLE=0), the simulation stops, otherwise it continues, as described. If HHT has been detected, and/or its position has been transferred to SPMGS, for every SPGMS it is examined whether there are some of them who can launch missiles at HHT. If there is any possible LAUNCH, it is executed, and it is examined if HHT is destroyed. The SPMGS LAUNCH scenario is depicted in **Figure 3**. The SPMGS missile launch is possible if HHT is in missile possible attack zone (PAZ, Section 2.3), and in time instant $t = T_2$, the inequality (5) is true:

$$D_{HHT-TARGET}(t = T_2) \ge D_{HHT-TARGETmin} \tag{5}$$

Where:

$D_{HHT\text{-}TARGETmin}$: minimal HHT distance to its TARGET, that qualify HHT mission accomplished.

SPMGS reaction time t_r (**Figure 3**) is the time interval from HHT acquisition to firing of the first missile.

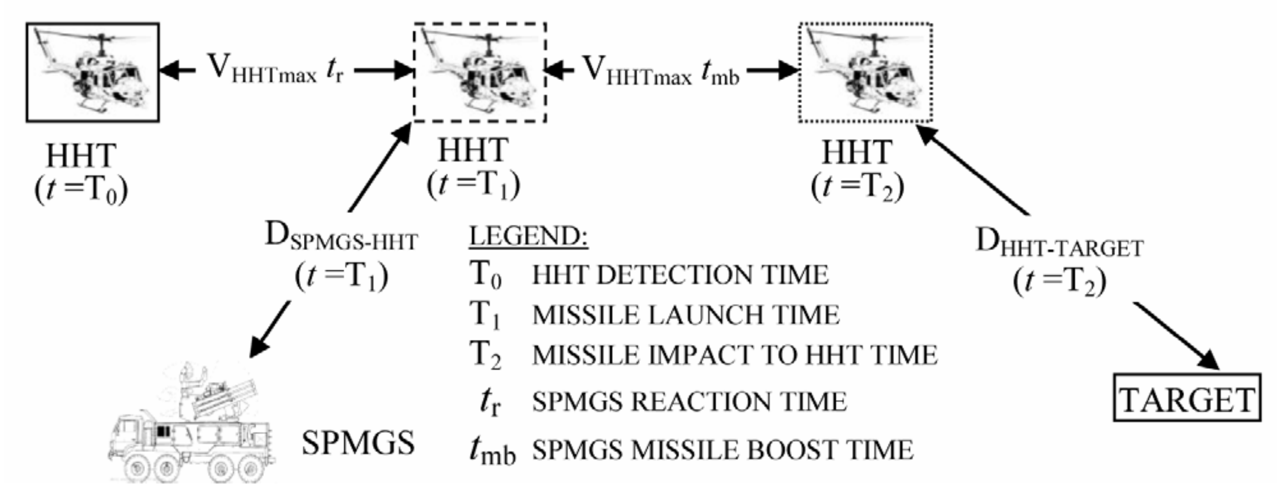

Figure 3. SPMGS LAUNCH scenario

If there is no more possible LAUNCH, for every SPMGS it is examined whether there are some of them who can open gunfire at HHT. The SPMGS GUNFIRE is possible if HHT is in gunfire possible attack zone (PAZ, Section 2.3). If there is any possible GUNFIRE, it is executed, and it is examined if HHT is destroyed.

If HHT is destroyed either by missiles, or by gunfire, the SUCCESS counter is increased by 1 (SUCCESS+1), the experiment termination counter is decreased by 1 (SAMPLE-1), and it is examined whether the experiment is over (SAMPLE=0). If it is over, the simulation stops, otherwise it continues.

If HHT is destroyed neither by missiles, nor by gunfire, the simulation clock is advanced by one of the command-information system's basic interval $\triangle t$, and the simulation continues, as described.

Primary performance measure in the simulation is the probability of success of territory cell defence, defined as:

$$p_{SUCCESS} = \frac{SUCCESS}{SUCCESS + FAILURE} \tag{6}$$

Where:

SUCCESS: counter of simulation passes, ended by successful TC defence – HHT destruction

FAILURE: counter of simulation passes, ended by unsuccessful TC defence – HHT survival

GPSS World simulation language (Minuteman Software, [14]) has been chosen for the simulator algorithm implementation, due to its suitability for discrete events system simulation and easy availability of the tool on the Internet.

4. CONCLUSION

Hybrid attacks are challenging pressures to which small and neutral countries are especially exposed, even out of conventional wars, officially declared between states.

Hybrid conflicts have elements of both conventional and irregular activities, so hybrid strategy will be required to combat against hybrid threat.

On tactical level, it is worth studying and devising new tactical procedures for using known conventional arms in the hybrid warfare environment.

The approach to discrete events simulation modelling of 3-dimensional territory cell defence by self-propelled missile-gun systems against a helicopter as a hybrid threat has been proposed in this paper.

A new simulation algorithm of a self-propelled missile-gun systems group, using swarming tactics and combined missile and automatic guns attack against helicopter has been developed and presented, as well as defined such system's performance measure, and possibility of the simulator realization.

Such a defence depends on a real-time information of the hybrid threat exact position, provided by the command-information system. Having in mind that a helicopter is a threat from the air, the new concept of 3-dimensional command information system parallax has been introduced, as the difference between helicopter's real position and its fake position, estimated from unreliable imperfect command-information system.

The authors believe that such simulators could be useful cost-effective tools for preliminary research of new tactical procedures, needed for application in future hybrid conflicts.

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