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General Approach to Counter Unmanned Aerial Vehicles

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Abstract

The following study is devoted to the problem of preventing offensive missions led with small Unmanned Aerial Vehicles (UAVs). The main goal of the paper is to familiarize the reader with a general methodology for counteracting offensive UAVs. In this paper, the authors describe counter UAV approach, which includes several stages, such as: the identification of threats, the development of prevention measures, active counteracting (including: detection, tracking, identification, evaluation, decision making and counteraction), evaluation and improvement of the anti-UAV counteraction system.
In the recommendations, the authors give two non-exclusive practical approaches to countering hostile UAVs: the offensive counter UAV and the defensive counter UAV, which concern wide range of different strategies from “destroy as many UAVs as possible” to “protect all high value assets from UAVs threats”.

Keywords: Unmanned Aerial Vehicle (UAV), offensive and defensive counteraction to UAVs, threats from hostile UAVs, protection of High Value Assets (HVA).

1. Introduction

The emergence of the Combat Unmanned Aerial Vehicles (UAV) caused changes in the its mission roles, which began to combine the tactics of manned reconnaissance and bomber aircrafts. From such missions as Recon (Reconnaissance), BDA (Battle Damage Assessment), FAC (Forward Air Control) and aerial spotting at the beginning, they evolved to SEAD (Suppression of Enemy Air Defense) Strike [1], CAS (Close Air Support) and Interdiction. Contemporary UAVs can even accomplish On-Call CAS [2].

Based on the Ukrainian experience, the most dangerous examples of hostile UAV using, beside reconnaissance, are aerial spotting [3, 4] and air strikes at ammunition depots [5]. And the other side of the coin is to counteract this new and

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effective weapon in the hands of the adversary. Ukraine faced this problem during Anti-Terrorist Operation (2014–2018) and Joint Forces Operation (2018–…) in Donbass.

There are more than 600 violation of Ukrainian air space by Russian UAVs from 2014, which has been officially confirmed [6]. And also, a lot of eyewitness accounts of such violations are recorded on everyday basis (on average 3 to 5 flights per day) [3, 4]. Though, there only near 80 of these violators were destroyed for this time (several of them, obviously, fell down with own technical failures) [7].

Considering the Russian hybrid war against Ukraine with the use of both military and terrorist tactics for UAVs, simple calculations show that each UAV performs in average from 8 to 70 flights for its life cycle (with a designed guaranteed life cycle of 100 flights). This fact eloquently indicates the urgent need to develop new methods of defeating them.

While shooting down large UAVs (such as Russian "Forpost") is identical to the same actions against piloted aircrafts and is carried out in the state air defense (AD) system, shooting down small UAVs (such as Russian "Orlan-10") with area defense missile systems is economically unprofitable.

The way of solving this problem is the development of proper agile counter-UAV subsystem inside the state AD system. So, the paper's aim is to give some insights for those who will be creating such subsystem and to design a kind of "roadmap" for them.

2. Counter UAV Methodology

The common AD methodology is described in [8, 9], but it was designed to contradict mostly to wide air operations and cannot be directly applied to the counter-UAV process.

With authors' refinements, this methodology can be shaped in counter-UAV subsystem comprised of several cyclical stages, as shown in Figure 1:

a) Readiness. Includes activities for analysis of threats and preventive measures to understand offender and protect HVAs.
b) Detection and Decision Making. Measures, which include activities such as detection, tracking, identification, threat evaluation and decision making.
c) Influence. Active countermeasures including destructive and non-destructive impacts on hostile UAVs.
d) Evaluation and improvement of the anti-UAV counteraction system.

a) Readiness

Identifying and distinguishing threats against a protected object. Aside from analyzing one's own vulnerabilities and risks, it is necessary to create a model of the offender's goals and courses of action.

It is also necessary to carrying out ceaselessly a set of organizational measures, aimed at misleading the enemy with regard to the actual location of troops in combat positions, reducing the efficiency of conducting ISR from hostile UAVs as much as possible. Such organizational measures that need to be carried out in the troops should include:

a) using different ways to camouflage and shield high value assets (such as the use of smoke and masking aerosols; the skillful use of protective features of the terrain by troops and military units etc. [10]);
b) the creation of a system of HVA decoys;
c) the restriction or prohibition of the use of wireless communication and mobile phones, as well as active GPS devices, etc.

b) Detection and Decision Making

The main problem in combating UAVs is detecting small and low-altitude targets. Indeed, the current level of UAV production technology (using of plastic, fiberglass, foam in their construction) can provide radar cross-section values from 0.1 to 0.005 m^2. In addition, the use of low-power economic engines makes their flights almost silent, which also interferes with the process of target detection, identification and tracking. Therefore, searching for and detecting small-scale UAVs requires the use of complex tools and equipment, running on diverse physical principles.

Now, for the detection of UAVs are used passive (such as radio, acoustic, built-in opto-electronic means on military anti-aircraft installations, air visual surveillance posts (air guards)), as well as active (such as radars).

There are several types of units in different Services with the same task – to counter UAVs, which they execute separately. So, the detection of the UAV electronic equipment, determination of operating frequency ranges (ELINT) are carried out by ground-based electronic intelligence systems. Electronic warfare units are responsible for detection and jamming hostile UAVs. Artillery reconnaissance has capabilities to detect UAVs and to destroy their ground control station (GCS).

Also, every military installation (base) has its air guards with communication and data transmission equipment and visual observation tools for detecting small-scale, low-contrast targets.

The first task in creation of counter-UAV system is to design Command and Control (C2) system with ability to unite information from all these systems for improving the overall quality of interaction and intelligence exchanging.

Such C2 system is responsible for the tracking process, during which a UAV is identified (friend-or-foe) and is assessed for potential threats. The decision on appropriate counteraction to offensive UAV is made, based on the threat level evaluation.

c) Influence

There are several ways to prevent negative effects caused by offensive UAVs on our sites. They can be such as destructive and non-destructive (hard and soft) influence; kinetic/non-kinetic destruction of UAVs, and/or signal repeater and/or ground control station (GCS), with/without the interception of UAV/information, information (cyber) impact, etc.

The most obvious method is physical destruction. Various weapons can be used for this purpose. Thus, small

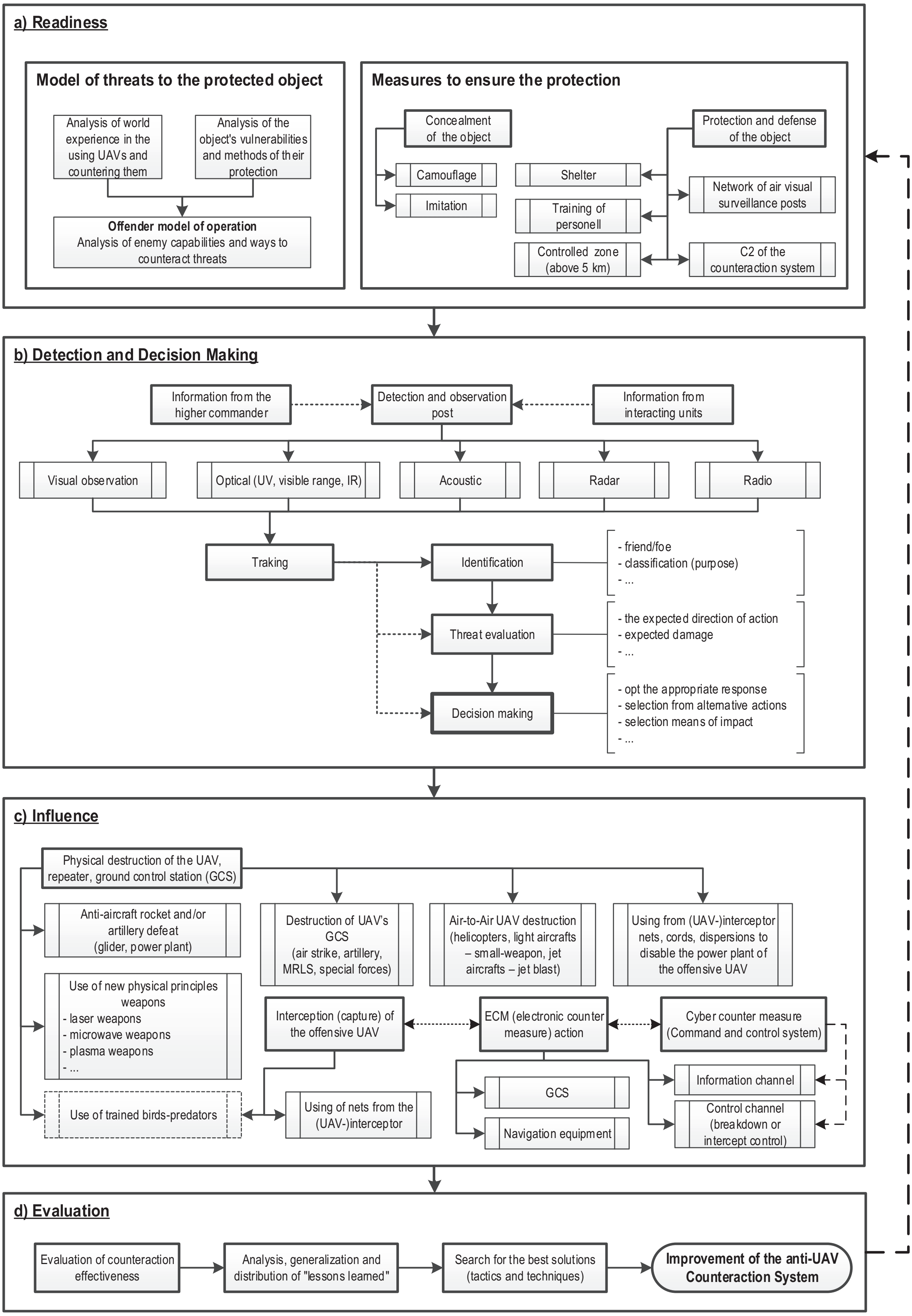

Figure 1: Counter UAV General Approach
Source: Martyniuk, Microsoft Visio

lightweights can be shot down with the help of small arms, anti-aircraft artillery, and it is expedient to use anti-aircraft missile systems to defeat large UAVs. The leading countries of the world are working on and creating EMI, microwave, laser, as well as conventional weapons [11, 12, 13], to destruct offensive UAVs.

The result of this method is fast and concrete, but the physical damages caused by hostile UAV prevent us from revealing of its intended mission.

So, the next method, Interception, is free from this disadvantage. Physical access to the captured UAV gives us an opportunity to disclose the foe's intentions.

Interception can be "hard" or "soft". "Hard" means a physical non-destructive impact on the hostile UAV to make it land within our area of responsibility. This could be performed by UAV-interceptor or even by a trained bird of prey [14, 15, 16, 17]. "Soft" interception is a cyber or electronic impact, as described below [18, 19].

Interference with electronic equipment (jamming) is another significant approach. As an alternative to physical destruction, the suppression of a UAV's electronic systems can force an offensive UAV to land or to fall. Some modern UAVs can independently perform some of these tasks, but almost all UAVs are still operated by a remote pilot, and the commands are transmitted over the radio channel. Thus, the suppression of the control channel by means of electronic warfare (EW) can, at least, hinder hostile task execution. Currently, it is not a common practice to equip UAV with an intelligent autopilot capable of taking control in the case of losing the operator's signal. In addition, loss of communication with the operator will result in an inability to transmit intelligence information, such as a video signal from the UAV camera. The fate of UAVs left without control depends on the party performing an interception.

In case of a loss of communication with the operator, some UAVs have an appropriate mode of operation. When the signal from the remote control is lost, the automation returns the UAV to a designated area where it can make a landing. In this case, the control system ignores all signals, and the movement to the specified area is carried out using satellite navigation. Using GPS, GLONASS or another navigation system, the aircraft can determine its own position in space, direction and range to the operator or aerodrome, and return to it. In order to prevent the "evacuation" of UAV, the means of electronic warfare should suppress not only the control channel, but also the signals of the navigation system.

As a result of the successfully "jamming" of all these signals, the foe, with high probability, will lose the equipment that has appeared in the area of the EW, with all its information (intelligence).

Nowadays, different types of AD means are in the units of different services, that significant decrease efficiency of cooperation by increasing the information exchange time.

So, the main task of Counter UAV system is to unite not only the detection and tracing means but also AD means under common C2 system.

d) Evaluation and improvement

On this stage the experience of each combat application is summarized, lessons learned are disseminated between all units, recommendation are created for improvement of the anti-UAV counteraction system.

3. Recommendations for creation of Counter UAV System

According to Ukrainian experience in counter-UAV actions in Donbass (2014–…), it is necessary to distinguish two non-exclusive practical approaches to countering hostile UAVs: the offensive counter UAV and the defensive counter UAV, which concern wide range of different strategies from "destroy as many UAVs as possible" to "protect all high value assets from UAVs threats". Wide range of criteria can be used for evaluation. Some possible of them are shown in table below.

3.1. Offensive counteraction to UAVs

The low effectiveness of the counteraction to small UAVs by area defense missile systems (also, it is too expensive) necessitate the development and implementation of special measures, both for their physical destruction and for counteraction to the intelligence, control and weapon UAVs onboard systems. Such a list of measures may include:

a) The creation of special groups of air-defense units, which include various types of short-range SAM systems, a forward area air defense gun system, MANPADS, which have relatively high intelligence and fire capabilities for small-scale targets and are intended exclusively for delivering damage to the UAVs;
b) The improvement (modernization) of existing assets of anti-aircraft weapons in order to increase the splash effectiveness of small-scale targets;
c) The development of perspective sophisticated anti-aircraft weapons designed to solve specific problems of detecting and defeating small-scale air targets, including UAVs (drones);
d) The development of specialized equipment for splashing small-scale air targets, based on unconventional ways of destruction and weapons on new physical principles;
e) The creation of a system of military measures to counteract intelligence and control systems, reducing effectiveness of hostile UAVs' mission.

For the effective counteraction to small-scale air targets, it is necessary to create a purposeful counteraction system (as part of the overall air defense system), which should include an active component (damage to the UAV by fire or by any other means from the ground and in the air) and a passive (non-destructive) component (a series of measures to counteract intelligence and control systems, and to reduce the UAV-mission effectiveness).

The destruction of the ground component of an unmanned aerial system (UAS), such as GCS, launch and maintenance

Table 1. Criteria for evaluation of counter-UAV system effectiveness

Approach **Protected object**	**Our task**	**Example of Criteria**	**Our result**
OFFENSIVE **JOA**	Restriction of air space violations in JOA: Destroy as many offensive UAVs as possible	$\min(N^{Lnch})$	Early prevention. Disabling of UAVs launching (destruction of lunching sites)
		$\max(N^{Dstr})$	Destruction of UAV in flight
	Air supremacy	$\frac{N^{Lnch} - N^{Dstr}}{N^{Lnch}} < 0.2$	Almost none of hostile UAVs can execute their mission
	Air superiority	$\frac{N^{Lnch} - N^{Dstr}}{N^{Lnch}} < 0.5$	Less than half of hostile UAVs can execute their mission
	Denying of offensive UAVs mission fulfillment toward HVA	$\min\,(\mathrm{E}^{\mathrm{w/oAD}} - \mathrm{E}^{\mathrm{wAD}})$	Capturing UAV before its mission
	Preventing taking/transmitting info (non-kinetic / kinetic), including cyber	$\min(I^{\mathrm{wAD}})$	Capturing UAV with information (intelligence), had been collected by them.
		$\frac{I^{\mathrm{w/oAD}} - I^{\mathrm{wAD}}}{\mathrm{w/oAD}} < 0.8$	Denying information transmission
DEFENSIVE **HVA**	Preventing HVA damage, protect all HVAs from UAVs threats	$\min\,(\prod_{i=1}^{M} k_i W_i)$	Reliable and sustainable existence of HVAs

JOA – joint operation area;
N^{Lnch} – number of launched UAVs;
N^{Dstr} – number of destroyed UAVs;
$\mathrm{E}^{\mathrm{w/oAD}}$ – effectiveness of hostile actions without AD system;
$\mathrm{E}^{\mathrm{wAD}}$ – effectiveness of hostile actions with AD system;
$I^{\mathrm{w/oAD}}$ – information which can be transmitted by hostile UAV without our actions;
I^{wAD} – information which can be transmitted by hostile UAV with our actions;
k_i – importance of *i*-HVA;
W_i – probability of *i*-HVA destruction;
$i(1 \ldots M)$ – number of HVAs.

sites, as well as UAVs before their launch, may be carried out by artillery, MLRS units and, by attack aircrafts. Since the launch and maintenance sites of small-scale UAVs are forced to deploy directly in the tactical zone near the forward edge of battle area and even on the battlefield, they can and must be set as a high priority target and be destroyed by fire units. The combat range of attack helicopters and close-support aviation also make it possible to reliably wipe out UASs' maintenance and launching units on the ground, along with all UAVs, before the start of their mission.

The destruction of elements of the UAS at their deployment sites should also be carried out by Special Operation Forces (SOF). An important part of this mission is also to find out the locations of UAS units, their strength, plans, and technical characteristics of GCS. Such measures are carried out by both technical means of ISR and covert intelligence. Performing the task of destroying the ground elements of UAS, in order to prevent the launch of the UAV, becomes particularly relevant due to the lack of efficiency of all the other means of reacting to UAVs with an extremely low reflection surface.

In order to defeat a UAV by fire or by any other means in the air, an anti-aircraft missile (artillery) fire system must be thoroughly organized, and it can only become effective if a series of special measures are taken in response to small-scale air targets. It should be created as a part of a common unified air defense system as a special subsystem of air defense to small-scale targets. Such targets include not only UAVs, but also high-precision weapons (guided bombs, cruise missiles, etc.).

The subsystem of air defense to small-scale targets include elements of ISR and warning systems, combat operations management, anti-aircraft missile and anti-aircraft artillery fire systems, a set of specialized anti-aircraft weapons, and so on.

The tasks of detecting, tracking small-scale UAVs and the dissemination of information on the coordinates of their flight should be solved jointly by all ISR units, with the creation of a single information space concerning with network-centered warfare strategy.

Naturally, in order to improve the efficiency of the search and detection of small-scale UAVs, it is necessary to use a set of tools on diverse physical principles. The detection of such UAVs should be carried out by passive means of ISR (radio, optic, acoustic), as well as active means (radar). As mentioned above, anti-aircraft searchlights and the network of visual observation posts may come in handy.

A system of anti-aircraft missile and artillery fire should be in line with the requirements. It must be carefully planned, built, and deployed considering the protective features of the terrain for troops, military units and high value assets.

It should be noted that the active defeat of the small-scale UAV by anti-aircraft means, those are in service nowadays, is possible only with great limitations and restrictions for the detection and firing on a UAV with a reflection surface of less than 0.01 m^2. Effectively targeting a UAV, which has a less reflective surface is practically impossible with ongoing anti-aircraft systems.

For reliable damage to the micro-UAV with anti-aircraft fire, it is necessary to develop and design specialized anti-aircraft weapon systems, may be based on new physical principles (laser, EMP, etc.).

The development of such new weapon systems is an extremely acute problem facing the military industry and weapon designers. The solution to this problem should be a challenge soon.

3.2. Defensive counteraction to UAVs

The protection of HVA from small UAVs should be carried out in the general air defense system, whose main criterion of efficiency should be distorted damage to a protected object.

There are several conclusions after the assessment of the current capabilities to counteract small UAVs. Command posts of ISR means of military units, which must provide anti-aircraft systems with time-sensitive information on the coordinates of air targets, when working on small-scale UAVs are ineffective. The detection range does not allow the higher-level staffs of air defense units to participate in the fire control of subordinate units, which significantly reduces the potential combat capabilities of military units as a whole. In such cases, decision making on firing (the launching of surface-to-air missiles) by air defense units must be carried out autonomously, by separate units, based on previous guidance provided earlier, according to their own observation means.

However, separate fire units, in the case of counteraction to small-scale air targets, have similar problems, which are caused by the specifics of the construction and UAV-led missions. Therefore, the effective damage to the UAV in the air is extremely complicated.

In order to solve this problem, it is proposed to create mobile mixed anti-aircraft groups (MMAAGs), that should have similar properties as prospective combined anti-aircraft systems and can apply different principles for detecting airborne attacks, and tracking and shooting down small-scaled air target. The main idea is to combine the properties of the various existing detection systems, methods of guiding, SAM and anti-aircraft artillery means of various types and placing them at common fire positions, in order to compensate the disadvantages of some by the advantages of others in various conditions. The feature of the use of MMAAGs to combat UAVs should be the possibility of creating the "hidden zone of fire".

The separate fire units of such groups can act in the most dangerous UAV flight areas of as moving ambushes among a set of HVAs. This results in unexpected air defense fire and increases the effectiveness as of the HVA's protection so of damage to small-scale UAVs.

In such groups, ROE and guidelines for interaction in the fire system of the small-scale UAVs counteraction should be pre-designed in advance. These instructions should specify the procedure for conducting the detection, tracking, identification and elimination of UAVs, the exchange of information between the anti-aircraft units and weapons on the coordinates of a UAV flight, the results of combat, the techniques of concentration and dispersal of fire, the assigned rockets (ammunition) consumption, as well as other issues regarding the specificity of air-defense combat for small-scale targets.

The hitting area of MMAAGs must be comprised in such a way that sectors of active and passive anti-aircraft weapons are superimposed on one another (for the possibility of firing one target with anti-aircraft weapons that use different methods and techniques of target tracking and rockets (ammunition) guidance, and in different ways are protected from EW interference).

The decision of which strategy (offensive, defensive or a combination thereof) to the termination of enemy's hostile action is most suitable in each situation depends on the resources available to each opposing party. Mostly, they include time, weapons, and personnel.

4. Conclusions

The given methodology shows way to synthesis of the Counter-UAV Subsystem in the state AD system. Such subsystem allows to integrate means and efforts of all units, which execute the task of UAV countering separately, in the state AD system under common C2.

At present, both HVA concealment from UAVs threats and physical destruction of hostile UAVs is necessary. Based on Offensive-Defensive strategies were refined tasks and goals for the Counter-UAV Subsystem. And the set of criteria was defined for wide range of countering strategies from "destroy as many UAVs as possible" to "protect all high value assets from UAVs threats".

Recommendation for creation of small mobile AD groups in Counter-UAV Subsystem is solving problem of efficient resources distribution and allows multiplying efforts of different types of counter-UAV means.

The approach given in the article is a roadmap, the first step to countering modern and future UAV tactics. So, developed system must be ready to deal with future challenges, such as UAVs' intellectual deployment in groups, swarm etc. [19, 20].

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