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COVERING THE DEAD ZONE OF RADIOLOCATION STATIONS WITH THE ELECTRO-OPTICAL SYSTEM

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Abstract. With the emergence of unmanned aerial vehicles (UAVs), the assignments of combating them has become significantly more relevant. After detecting and identifying UAVs by radilocation stations, it is necessary to take measures to neutralize them. In the paper, a mathematical model of covering the dead zone of radiolocation stations with an electro-optic system for the effective detection of UAVs was established and a comparison of dead zone was made on specific examples. The aim of the research work is to construct a mathematical model of minimizing the dead zone of the radiolocation station by placing an electro-optical system on the visual observation post. The following problems are solved in the paper: analysis of the characteristics of the radiolocation field; development of a mathematical model to evaluate how the dead zone changes depending on the number of electro-optical devices, their location and orientation relative to the radiolocation station; evaluation and comparison of the dead zone through an electro-optical system placed to the visual observation post. To solve the problems, the following research methods are used: theoretical analysis, mathematical modeling, comparison analysis. The following results were obtained: when covering the dead zone of radiolocation stations with one electro-optical system placed on a visual observation post, its volume decreases by 1.35 times, when it is covered by two electro-optical systems placed on one visual observation post, its volume decreases by 1.30 times, when it is covered with two electro-optical systems placed on a visual observation post opened in two different directions its volume decreases by 1.20 times.

Keywords: unmanned aerial vehicle, dead zone, radiolocation area, effective reflection area, radiolocation station, electro-optical system.

AMS Subject Classification: 91F20.

1. Introduction

The experience of local wars and military conflicts around the world shows that in order to minimize the loss of manpower in wars and to make operations more effective, operations conducted without the participation of manpower will be more preferred in future wars. Thus, the wide use of reconnaissance UAVs and blow UAVs in conducting combat operations has shown their effectiveness [7].

One of the main problems for air defense systems is the development of UAVs. Timely detection of small-sized, relatively silent and low-altitude UAVs by Air Defense Systems (ADS) becomes difficult. Special colors and protective layers are used in the development of UAVs, which make them difficult to detect by visual observation posts or radiolocation stations. [5].

There are various methods for detecting UAVs. Each method differs from each other in its advantages, disadvantages, application conditions, accuracy and other parameters. One of the main methods of detecting UAVs is detection by radiolocation stations.

Radiolocation stations (RLS) are an active means of monitoring the airspace. Airspace surveillance and air target detection using radiolocation stations within a unified air defense system is a fairly common traditional method. During the Patriotic War, the role of radiolocation stations in controlling the airspace of Azerbaijan was great. Thus, RLSs have duly fulfilled the problems of transmitting information to anti-aircraft missile complexes (AMK) or other types of troops for the detection, identification, and destruction of UAVs that have entered our airspace [6,7,12].

Based on the analysis of local wars and conflicts in recent years, the 2020 Patriotic War, as well as the ongoing Russia-Ukraine war, it was determined that in order to fight against UAVs, it must first be detected in time. Against the modern UAVs used by the Azerbaijani Army in the Patriotic War, the detection stations in the armament of the Armenian Army were old, the number of those stations was small, and due to the weak combat skills of the personnel, most of the UAVs used by the Azerbaijani Army could not be detected in time. As a result of the correct combat tactics of Azerbaijan in the first days of the war, the locations of detection stations and anti-aircraft missile complexes in the armament of the Armenian Army were quickly discovered and neutralized. As a result, the air superiority in the Patriotic War completely went to the side of Azerbaijan [1,2,8,13].

In order to combat UAVs more effectively, it is important to detect them quickly at a long distance also as well as in the dead canyon [9].

A dead zone (DZ) is a such part of the space above a radiolocation station which is beyond radiolocation observation and where RLS cannot detect air targets (fig.1). The presence of a dead zone is determined by the appropriate selection of the vertical orientation diagram of the radar station, which depends on the relief of the area in the area of influence of the station, the nature of the position, the height of the antenna and the technical parameters of the RLS. To detect and track the air targets by this RLS in a dead zone it is not impossible.

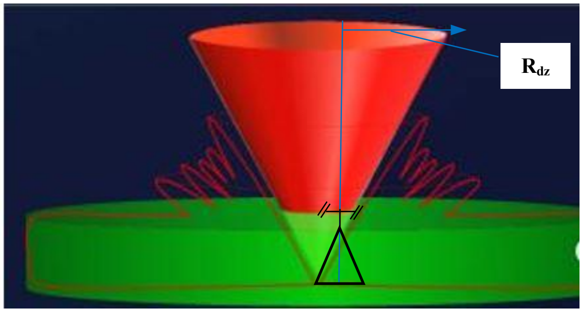

Figure 1. Dead zone (Zone over RLS)

The field of vision of radiolocation stations is determined by the design of the RLS antenna and its operating characteristics (wavelength, transmission power and other parameters) [15].

The analysis of recent local wars and conflicts, as well as the Patriotic War, the results of theoretical studies and practical experiments show that the existing means of combating UAVs are ineffective. Thus, there are difficulties in reliable and timely detection of UAVs, especially small-sized UAVs, in a large zone using existing intelligence tools. This is due to the following: the limited capabilities of existing radiolocation stations to detect UAVs of small size and low speed flying at low altitude; inability to reliably and timely detect UAVs at the designated distance and altitude through optical devices on the visual observation posts (VOP).

Taking into account the characteristics of UAVs and the indicated problems of combating them, it is advisable to modernize existing radiolocation stations, develop specialized small-sized radiolocation stations, and provide visual observation posts with automated electro-optical reconnaissance devices for the timely and effective detection of UAVs in the dead zone.

Taking into account the relatively short detection ranges of small-sized UAVs, in order to fight with them in a dead zone, it is considered appropriate to equip the designated units and the units guarding critical objects with small-sized (specialized) RLS, and the VOPs with an electro-optical system.

The use of existing and promising electro-optical systems in the direction of the likely flight of the enemy, in VOPs, allows timely detection of UAVs in the dead zone, recognition of their class, type and current nature of their movements.

In the future, the mentioned electro-optical systems can be replaced by more improved models. Thus, examples of electro-optical systems have already been developed, which can detect small UAVs in time.

In order to effectively detect UAVs in a dead zone, when creating a radiolocation area, it is necessary to pay attention to the battle position of radiolocation stations and the number and placement of visual observation posts (VOP) equipped with an electro-optical system in the area. In this work in order to increase the effectiveness of radiolocation reconnaissance of UAVs in the dead zone determination of the number of visual observation posts equipped with an electro-optical system, which is one of the methods of formation of the battle position, was considered and the report of the reduction of the dead zone through the electro-optical system is shown with specific examples.

2. Problem statement

To reduce the risk of a drone attack on a radiolocation station, control of its dead zone using an electro-optical system can be organized in various options. These options differ from each other mainly depending on where the electro-optical control devices are placed in the area relative to the radiolocation station, how the electro-optical device is directed and its viewing angle. We will assume that the applied electro-optical devices have the same characteristics. It is clear that the introduction of an electro-optical device will reduce the dead zone of the radiolocation station.

The problem set in this research is the development of a mathematical model to evaluate how the dead zone changes depending on the number of electro-optical devices, their location and orientation relative to the radiolocation station.

3. Dead zone assessment model

To describe the mutual location of the radiolocatin station and the electro-optical control devices, let us introduce the Oxyz positively oriented rectangular coordinate system with respect to the ground [14, p.73], traditionally, the Oz axis can be considered perpendicular to the Earth's surface, pointing vertically upwards. For the sake of simplicity, we will assume that the radiolocation station, of which dead zone is studied, is located at the point O, and the axis of its dead zone, which is considered as a straight circular cone, is directed along the axis of Oz.

Let us denote the height of the radiolocation station's dead zone as h, and its characteristic angle as α (Fig. 1), then the section cone K_0, which represents the dead zone of this station, can be written as follows:

$$K_0 = \left\{(x, y, z) |\, x^2 + y^2 \le z^2 \operatorname{tg}^2 \frac{\alpha}{2}, 0 \le z \le h\right\}.$$

As in [9], we will assume that the evaluation of the dead zone is performed by calculating the volume of the corresponding spatial figures.

It is clear that the dead zone volume of a separate radiolocation station with the above characteristics is calculated by the following formula [3, s.347]:

$$V_0 = \iiint_{(x,y,z)\in K_0} dxdydz = \pi \operatorname{tg}^2 \frac{\alpha}{2} \int_0^h z^2 dz = \frac{\pi}{3} h^3 \operatorname{tg}^2 \frac{\alpha}{2}. \qquad (1)$$

Suppose that $k \geq 1$ number of electro-optical devices are applied, let's number them as $i = 1, 2, \ldots, k$. Let's denote the coordinates of the point where the i-th device is located as x_i, y_i, z_i . It is assumed that the devices are of the same type and their viewing angle φ is known.

Let's assume that, i-th device $\boldsymbol{n}_i = (n_{xi}, n_{yi}, n_{zi})$ directed in the direction of the unit vector ($\|\boldsymbol{n}_i\| = 1$). Then the axis of the field of view of this device will be a straight circular cone directed in the direction $\boldsymbol{n}_i = (n_{xi}, n_{yi}, n_{zi})$. To describe the set of points belonging to the control circle of the device, let's first write the equation of the conic surface.

For each formal number $s \geq 0$ the coordinates of the point at a distance s from the coordinate origin in the $\boldsymbol{n}_i$ direction are $s\boldsymbol{n}_i = (n_{xi}s, n_{yi}s, n_{zi}s)$. Let's write the equation of the plane perpendicular to the vector $\boldsymbol{n}_i$ and at a distance s from the point (x_i, y_i, z_i):

$$n_{xi}(x - x_i) + n_{yi}(y - y_i) + n_{zi}(z - z_i) = s. \tag{2}$$

The circle taken at the intersection of the plane (2) and the cone appears at an angle φ from the view point. This means that the radius of the circle obtained in the cone section is $s \cdot \operatorname{tg}\frac{\varphi}{2}$. If we write the equation of the sphere corresponding to that circle, we obtain

$$(x - x_i - n_{xi}s)^2 + \left(y - y_i - n_{yi}s\right)^2 + (z - z_i - n_{zi}s)^2 = s^2 \operatorname{tg}^2 \frac{\varphi}{2} \tag{3}$$

Thus, the set K_i, which represents the viewing cone of the device, is given by the system (2)-(3), which depends on the parameter $s \geq 0$. Finally, if we take into account the arbitrariness of the coordinates x_i, y_i, z_i of the point where the device is located, the system (2)-(3) can be written as follows:

$$K_i = \Big\{n_{xi}(x - x_i) + n_{yi}(y - y_i) + n_{zi}(z - z_i) = s,$$

$$\left((x - x_i) - n_{xi}s\right)^2 + \left((y - y_i) - n_{yi}s\right)^2 + \left((z - z_i) - n_{zi}s\right)^2 \leq s^2 \operatorname{tg}^2 \frac{\varphi}{2}, s \geq 0\Big\}.$$

As a result of organizing control through electro-optical devices with given characteristics in order to estimate how much the dead zone of the observed radiolocation station has changed, it is necessary to calculate the volume of its part that remains outside the viewing zone of the devices and compare the obtained result with the volume obtained from formula (1). It is easy to see that the out-of-control part of the radar station can be written mathematically in the form of the following set:

$$K = K_0 \setminus \left(\bigcup_{i=1}^{k} K_i \right).$$

Then the following formal formula can be written to calculate the required volume:

$$V = \iiint_{(x,y,z)\in K} dxdydz. \quad (4)$$

Comparing the volumes calculated by formulas (1) and (4) depending on the applied number of electro-optical devices and different orientation options allows choosing the considered rational option. Obviously, the ratio $\lambda = \frac{V_0}{V}$ can be regarded as a quantity that shows how many times the dead zone is reduced.

4. Examples for placement options

Example 1: Let's assume that the RLS dead zone angle $\alpha = 130°$, the height at which a dangerous UAV can enter the RLS dead zone is $h \leq 20\ [km]$. For UAV detection purposes 1 electro-optical system is installed to a visual observation post at the distance of $L_0 = 500\ [m]$ from the RLS and $H_0 = 5\ [m]$ above the RLS level (Fig. 2). If the detection distance of the system is $L_v = 40\ [km]$, and the viewing angle is $\varphi = 60°$, if the electro-optical device is directed to the middle line of the dead slot at an angle of $\theta = 30°$ to the horizon, let's evaluate the what times decreases of the unobserved part of the dead zone in different options. The results are given in the table below.

$L_0\ [m]$	$H_0\ [m]$	$L_v\ [km]$	φ (°)	θ (°)	λ
200	5	40	60	30	1,19
500	5	40	60	30	1,20
1000	0	40	60	30	1,20
1500	0	40	60	30	1,21
200	0	40	85	30	1,35

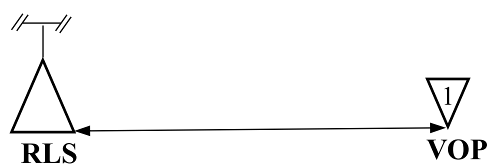

Figure 2.

Example 2: Let's assume that the RLS dead zone angle $\alpha = 130°$, the height at which a dangerous UAV can enter the RLS dead zone is $h \leq 20\ [km]$. For UAV detection purposes 2 electro-optical system are installed to a visual observation post at the distance of $L_0 = 500\ [m]$ from the RLS and $H_0 = 5\ [m]$ above the RLS level (Fig. 3). If the detection distance of the system is $L_v = 40\ [km]$, and the viewing angle is $\varphi = 60°$, if the electro-optical devices are directed to the middle line of the dead slot at an angle of $\theta_1 = 30°$ and $\theta_2 = 60°$ to the horizon, let's evaluate the what times decreases of the unobserved part of the dead zone in different options. The results are given in the table below.

$L_0\ [m]$	$H_0\ [m]$	$L_v\ [km]$	φ (°)	θ_1 (°)	θ_2 (°)	λ
200	5	40	60	30	60	1.27
500	5	40	60	30	60	1.28
1000	0	40	60	30	60	1.28
1500	0	40	60	30	60	1.29
200	0	40	60	30	85	1.30

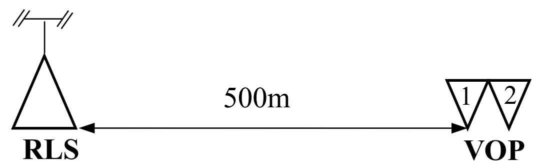

Figure 3.

Example 3: Let's assume that the RLS dead zone angle $\alpha = 120°$, the height at which a dangerous UAV can enter the RLS dead zone is $h \leq 20\ [km]$. In order to detect the unmanned aerial vehicle, 2 visual observation posts (VOP) were opened at the coordinates (200;0) [m] and (-200;100) [m], with 1 electro-optical system for each VOP, total of 2 electro-optical system has been placed (Fig. 4). System's detection distance is $L_v = 40\ [km]$, viewing angle is $\varphi = 60°$. The devices of the electro-optical system are directed from the central axis to the right at an angle of $\gamma_1 = 5°$ and to the left at an angle of $\gamma_2 = -5°$, both at an angle of 80° with respect to the horizon. Taking into account these, let's evaluate the what times decreases of the unobserved part of the dead zone. The results are given in the table below

$(x_1; y_1)\ [km]$	$H_1\ [m]$	$(x_2; y_2)\ [km]$	$H_2\ [m]$	θ_1 (°)	θ_2 (°)	γ_1 (°)	γ_2 (°)	λ
$(200; 0)$	0	$(-200; 100)$	0	80	80	-5	5	1.1[illegible]
$(200; 0)$	10	$(-200; 100)$	10	80	80	5	-5	1.1[illegible]
$(200; 0)$	0	$(-200; 100)$	0	70	70	5	-5	1.2[illegible]
$(200; 0)$	10	$(-200; 200)$	10	70	70	5	-5	1.1[illegible]
$(200; 0)$	0	$(-200; 200)$	0	70	70	10	-10	1.1[illegible]

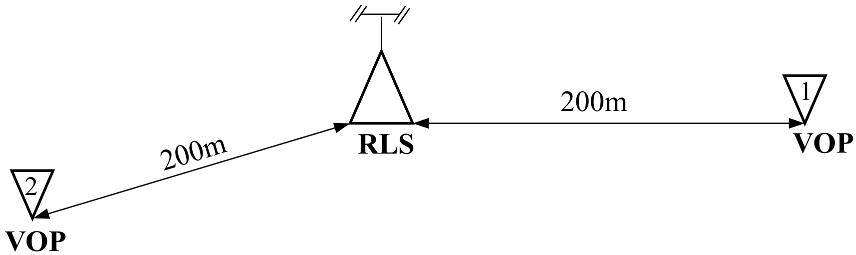

Figure 4.

Thus, the total values of the quantity (λ), showing how many times the radiolocation station's dead zone is reduced, are given in the tables.

5. Conclusion

In the paper is investigated the problem of detecting of the enemy's unmanned aerial vehicles flying in a dead ravine in the direction probable flight by means of an electro-optical system placed on a visual observation post. The angle of view of the electro-optical device, the detection distance, the orientation relatively to the central axis of the RLS, the angle of the dead canyon of the RLS, the height at which the UAV can enter the dead canyon of the RLS, the number of electro-optical system for the detection of the UAV and considering how far they are located, we calculated that it is possible to detect UAVs in a dead zone with an electro-optical sytem placed on a visual observation post.

Thus, when covering the dead canyon of radiolocation stations with one electro-optical system placed on a visual observation post, its volume decreases by 1.35 times, when it is covered by two electro-optical systems placed on one visual observation post, its volume decreases by 1.30 times. And its volume decreases by 1.20 times when it is covered with two electro-optical systems placed on a visual observation post opened in two different directions. From here we can conclude that based on the angle of view of the electro-optical system it can be considered more effective to cover the dead zone with two electro-optical systems placed at one visual observation post in the direction of the probably flight of enemy.

References

1. Aliev F.A., Larin V.B., Velieva N.I., Algorithms of the Synthesis of Optimal Regulators/ Outskirts Press, (2022), 412 p.

2. Aliev F.A., Maharramov R.R., The detection of small unmanned aerial vehicles (UAV) by the radar stations. Proceedings of the 8 th International Conference on control and optimization with industrial applications. 24-26 August, (2022), Baku.
3. Dombrovsky V.A. and other. Higher mathematics: Textbook / V.A. Dombrovskyi, I.M. Kryzhanivskyi, R.S. Matskiv, F.M. Mygovich, V.M. Nemish, B.S. Okrepky, G.P. Khoma, M. Shelestovska. I.; edited by Shinkarik M.I. – Ternopil: Karpyuk Publishing House, (2003), 480 p.
4. Eremin G.V., Cherny S.N., The system for struggle unmanned aerial vehicles - a new technical level and an integrated approach, Military Thought, No.7, (2022), pp.32-40.
5. Hashimov E.G., Maharramov R.R., Methods of effective detection of small-size UAVs, Second Karabakh war as a new generation war. Materials of the international scientific-practical conference dedicated to the anniversary of the victory in the 44-day Patriotic war, October 21-22, (2021), Baku, p.34.
6. Hashimov E.G., Maharramov R.R., Methods of effective detection of unmanned aerial vehicles, Problems of informatization, abstracts of reports of the 9th international scientific and technical conference, Volume 1. - Cherkasy - Kharkiv - Baku - Bielsko-Bialya: November 18 - 19**,** -(2021), c.118-119. URL: https://repository.kpi.kharkov.ua/server/api/core/bitstreams/b024598b-3c0d-4c71-b090-f631ee7d7e75/content .
7. Hashimov E.G., Maharramov R.R., Methods of effective influencing UAVs, Modern directions of development of information and communication technologies and management tools. Materials of the 10th International Scientific and Technical Conference, April 9-10, 2020. Volume 1. Baku-Kharkiv-Zhilina, (2020), c.27
8. Hashimov E.G., Maharramov R.R., Prospects for the development of air defense systems against UAVs, Modern trends in the development of information and communication technologies and management tools. Abstracts of reports of the eleventh international scientific and technical conference on April 8-9, 2021. Volume 1: sections 1, 2 Baku – Kharkiv – Kyiv – Zhilina, (2021),c.31-32.
9. Hashimov E.G., Maharramov R.R., Muradov S., Katekhliyev V., Methods of detection of UAVs acting on dead canyon by means of RLSs. Republican scientific-practical conference dedicated to the

2nd anniversary of the victory in the 44-day Patriotic War. Baku, November 2-3, (2022), pp.176-178.

10. Hashimov E.G., Maharramov R.R., Sabziev E.N., Pashaev A.B., Assessment of dead zone of jointly operating radars, Communication, telecommunications and radio engineering. Control, Navigation and Communication Systems, No. 3, (2023), pp.171-175. http://journals.nupp.edu.ua/sunz/article/view/3017/2415.
11. Maharramov R.R., Analysis of small-size UAV detection methods, Military knowledge - journal , No.2, (2022), pp.14-19.
12. Maharramov R.R., Detection of UAVs by radiolocation stations. "Azerbaijan in the post-war period: new approaches and perspectives in the construction of the army" republican scientific-practical conference dedicated to the 99th anniversary of the Great Leader Heydar Aliyev, Baku, May 12-13, (2022), pp.42.
13. Maharramov R.R., Hashimov E.G., Effective influence to small-sized UAVs with radio-electronic means of struggle. The development strategy of the Republic of Azerbaijan dedicated to the 100th anniversary of the Great Leader Heydar Aliyev: potential opportunities and new challenges republican scientific-practical conference. Baku, May 11-12, (2023), pp.20.
14. Tomusyak A.A., Trokhymenko V.S., Shunda N.M., Geometry, Part 1: Analytic geometry, Vinnytsia, (2002), 244 p.
15. What is a RLS detection dead zone and methods of it determine? https :// studfile. net/ preview/8961005/page:11/. 21.08.2019