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Assessment of Invisible Areas and Military Objects in Mountainous Terrain

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ABSTRACT

During war activities, the evaluation of invisible areas and military armours in mountainous terrain is very important for assessment of operational-tactical situation in battlefield. This information can be used for prevention of an enemy sudden attack. In given paper, the quantitative method of the invisible areas assessment and military objects in mountainous terrain are developed and offered by using unmanned aerial vehicle (UAV). The probabilities of invisible area or enemy object detection are calculated by using 1 and *n* UAVs. Previously obtained data by ArcGIS software (GIS technology) has been used for calculations and evaluations the number of invisible areas and military objects. The analysis of the dependence of revealing effectiveness, localisation areas and military objects on the number of UAVs has been carried out. It is more efficient to use one UAV for quantitative analysis of invisible areas, but it is more efficient to use several UAVs for detection of armoured vehicles and military objects. Our experiments in mountainous conditions had shown that at flight height 300 m and battle-front 2.5 km putting 3-5 UAVs is real. In this case, all of them perform operational mission and return to base. Finally, from the outcome of this study, the offered method can be applied for any mountainous conditions, for creation of a simulation and training UAVs war-game software.

Keywords: Hidden object; Invisible area; Military armours; Probability; Quantitative analysis; Unmanned aerial vehicle

NOMENCLATURE

N	The number of detected invisible areas or enemy objects
P	Probability of invisible area or enemy object detection
ρ	Distribution density of invisible areas or enemy objects on battlefield in km^{-1}
S_o	Size of reconnaissance area in km^2
P_c	Probability of object camouflaged on the background of mountain landscape
K	Factor of camouflage level of an object
ξ	Likelihood degree of false positions
η	The number of false hidden areas (objects) per one real area (object)
P_n	Probability of invisible area or enemy object detection by *n* UAV
n	The number of reconnaissance UAV
P_1	Probability of area or object detection (highlighted) by single UAV
m	Number of potential invisible areas or objects in reconnaissance area
S_o	Total area of reconnaissance region (km^2)
$L_{\parallel}$	Length of the reconnaissance area (km)
$L_{\perp}$	Width of optical system view area, that is, a width of the reconnaissance area (km)
t	UAV flight duration in reconnaissance area (h)
V	UAV flight speed (km/h)
T	Maximum UAV flight duration (h)
t_1	UAV flight duration from take-off point to front of reconnaissance area (h)
SS	Distance from UAV take-off point to front of reconnaissance area (km)

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1. INTRODUCTION

By using the tactical features of the area gives the opportunity for the high effective application of technology, confidential of manoeuver and enemy fire defense. The features of the area are defined with its relief, local and other geographical objects. The detection of invisible areas, military objects and armors in mountain terrain is very important for assessment of operational-tactical situation in battlefield. This information can be used for prevention of an enemy sneak attack. For this goal the various methods and technologies are used: Geography information systems (GIS) technology[1-3], photogrammetry method[3], seismic-location method[4] etc. Large obstacles (large tracts of forest, high hills, mountains, etc.) exaggerate this problems and cause the importance of unmanned aerial vehicle (UAV) application. For this reason, UAV is used widely for quantitative assessment of invisible areas and military objects in real battle situation[5,6]. UAV operations support battlefield commanders as they plan, coordinate, and execute operations. Other UAV missions support the maneuver commander by contributing to the effective tactical operations of smaller units. UAV system has remote video terminals and operations video enhanced receiver, portable ground control stations, and helps to set the conditions for the current and future forces success.

In the paper, the number of the invisible (hidden) areas, military objects and armors calculation on mountain terrain in the distance from observation post *A* to enemy post *B*, which can be detected by one or several UAVs, has been carried out for determination and comparison of the reconnaissance UAV possibilities. Flat country offered to the probabilistic analysis[6] has been used as basis method for these calculations for mountain conditions.

The calculations have been executed for one specifically taken mountain terrain where the analysis of hidden areas was carried out previously by using GIS technology[1,2].

2. METHODOLOGY

UAV reconnaissance missions obtain information about tactical activities and enemy resources. The number of invisible areas or enemy military objects, the locations of which can be detected, depends on some parameters: the kind of battle activities; the number of UAV reconnaissance; the distribution density of invisible areas in battlefield; the size of battlefield; the size of surveillance area by optical-electronic device; the probability of invisible areas or enemy objects detection. During surveillance of mountain terrain, it should be taken into account next factors, too: the height of terrain from observation post; the height of terrain from enemy location; the level of terrain invisibility, presence of forests, bushes, etc.

In addition, it should be taken into account camouflaging of military objects by natural mountain shelters. The number of invisible areas or enemy objects detected in the battle theatre by UAV with single flight can be calculated by Eqn. (1)[6,7]:

$$N = P \cdot \rho \cdot S_o \quad (1)$$

The probability of invisible area or enemy object detection *P* depends on the probability P_1 of object highlighted (detected) on the background of mountain landscape during single UAV flight. In turn, P_1 depends on the information content about sought-for area or object.

If the information content displayed on a screen of the UAV control post is sufficient for confirmation this object, then $P_1 = 1$. Therefore, the probability of object detection by using optical-electronic device of UAV can be determined by Eqn. (2)[6,7]:

$$P = P_c \frac{1-K}{1-\xi \cdot \eta} \quad (2)$$

For the probability of object camouflaged on the background of mountain landscape during UAV flight can be adopted that $P_c = 1$.

In present case, it can be adopted that the covering area of forests, bushes or big stones on investigated mountain terrain, which really camouflage the invisibility level of terrain, on the height above sea level of 2500 m - 2900 m is equal to 5 per cent, then $K = 0.05$; it can be adopted that $\xi = 0.9$ and $\eta = 0.01$.

The application of digital photogrammetry helps us to carry out our experiments and calculations for real conditions, to determine the invisible and visible areas of some mountain terrain of the Azerbaijan Republic, to estimate coefficients K, ξ and η, to plane and to determine UAVs flights. In conditions of other countries, the coefficients can be diverse.

After calculation by using Eqn. (2) we obtain $P = 0.96$

Depending on the conditions, a reconnaissance flight of UAV in surveillance area can be carried out by several UAV of the same type, so the Eqn. (2)[6,] changes to:

$$P_n = 1 - (1 - P_1)^n \quad (3)$$

The distribution density of invisible areas or enemy objects in battlefield can be determined as ratio of common number of potential invisible areas or objects to total area of reconnaissance area, that is, to battlefield area:

$$\rho = \frac{m}{S_o} \quad (4)$$

The size of reconnaissance area, where UAV carries out a flight, depends on technical features of UAV optical system and flight parameters: a view angle of optical system, a flight height, a flight endurance, a UAV speed and a distance from take-off point to front of reconnaissance area. The total size of reconnaissance area S_o is calculated by Eqn. (5):

$$S_o = L_{\parallel} \cdot L_{\perp} \quad (5)$$

The length of the reconnaissance area is calculated by using Eqns. (6) - (8).

$$L_{\parallel} = t \cdot V \quad (6)$$

$$t = T - 2 \cdot t_1, \quad (7)$$

where *T* is the maximum UAV flight duration.

$$t_1 = \frac{SS}{V} \quad (8)$$

3. RESULTS AND DISCUSSION

The height relief outline of invisible and visible areas of some mountain terrain in the Azerbaijan Republic has been obtained and investigated experimentally by ArcGIS software (GIS technology) as shown in Fig. 1[1,2].

Let us consider the UAV flight chart as shown in Fig. 2 in mountain terrain between points *A* and *B* obtained from Fig. 1:

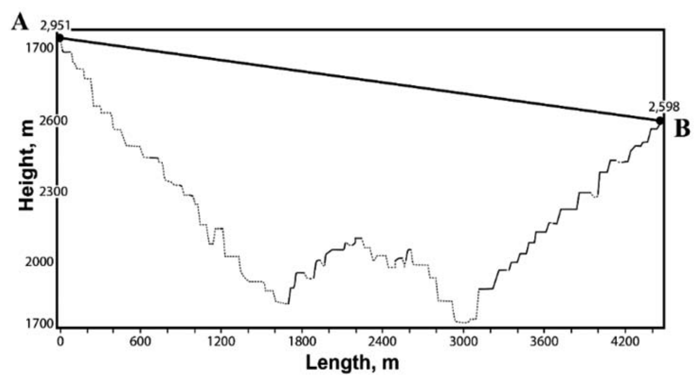

Figure 1. The height relief of visible (solid line) and invisible (dash line) areas between observation point A and target point B; bold line is observation one.

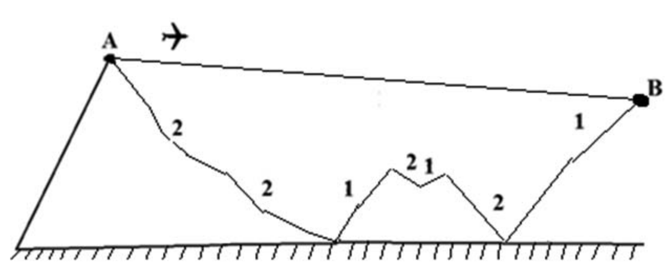

Figure 2. UAV flight chart between points A and B.

1 – visible areas, 2 – invisible areas (from point *A*). By using above indicated method, let us estimate a number of invisible areas, armoured vehicles and military objects located between points *A* and *B*, which can be detected by one or several (for instance, 10) UAV.

'Trimble UX5 HP' UAV has been taken for consideration[8,9]. This UAV 'allows to quickly create a high quality orthomosaics and 3D models for applications such as survey grade mapping, field leveling, site and route planning, progress monitoring and asset mapping'[8,9]. Some UAV performance characteristics are shown in Table 1.

Table 1. 'Trimble UX5 HP' UAV performance characteristics

Performance characteristics	Value
Maximum ceiling	5000 m
Endurance (T)	40 min
Range	52 km
Cruise speed	85 km/h
Flight height	300 m
Digital camera	"Sony İLCE-7R" 36 MP mirrorless full frame, 15 mm lens
Area/flight (S),	6.5 km^2 (flight height 300 m)

From Table 1 we can see that for 15 mm lens at flight height 300 m the area/flight equals S = 6.5 km^2 (see Fig. 3)[8], and $L_\perp$ = 2.55 km.

Let us take SS = 10 km and V = 85 km/h, then by using Eqns. (5) - (8) we obtain:

$$t_1 = \frac{SS}{V} = 0.12 \text{ h}$$

$$= T - 2 \cdot t_1 = 0.67 - 0.24 = 0.43 \text{ h}$$

$$L_{||} = t \cdot V = 0.43 \cdot 85 = 37 \text{ km}$$

$$S_o = L_{||} \cdot L_\perp = 94 \text{ km}^2$$

$$S_o = 94 \text{ km}^2$$

From analysis of information given in[1,2] as shown in Fig. 1 we can assess that $\rho = 0.98$ km^{-1}.

Then we can calculate from Eqn. (1) that by using one UAV we can detect

$N_1 = P \cdot \rho \cdot S_o$ = 88 invisible areas.

If we use 10 identical UAVs then, based on Eqn. (3) we

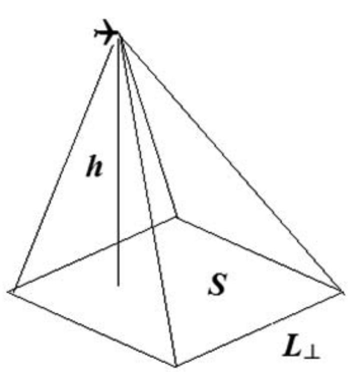

Figure 3. The chart of the area/flight at observation UAV flight.

obtain N_{10} = 92. So, the detection efficiency of invisible areas is not too increased, and it is reasonable to use one UAV.

Now, let us admit that there are 10 units of armoured vehicles per 1 km^2 of invisible area. Let us consider that a factor of camouflage level of armoured vehicles K = 0.9, a likelihood degree of false positions ξ = 0.9, a number of false hidden η = 0.01, then the detection probability of armoured vehicles by one UAV in accordance with Eqn. (2) P = 0.1.

The number of hidden armoured vehicles is detected during one UAV flight in accordance with Eqn. (1) N_1 = 94 units. If we take 10 identical UAVs then, in accordance with Eqn. (4) N_{10} = 611 units. That is, it is more efficienct to use 10 UAVs for detection invisible armoured vehicles.

The obtained results could be explained through if we use initial GIS information about terrain then the probability of one UAV detection of the invisible areas increases. Therefore, the application of 10 UAVs does not improve much the probability of invisible areas detection. We take into account that the probability of revealing of one armoured vehicle is less than the probability of revealing of one invisible area. Therefore, if we solve a problem of the camouflaged armoured vehicles detection on the invisible areas, it is natural that if we use several UAVs then we can detect more camouflaged armoured vehicles or military objects.

It should be noted, in the Azerbaijan Republic the real war activities had shown that it is not a hypothetical occurrence of multiple objects. The high cruise speed, the high flight height, unexpectedness, the flight noiseless, the sky blue colour of UAV, fully automated flight, the geometrical shape and the special structural material of UAV provide the upper level of UAV defence. Our experiments in war conditions (unpublished) had shown that at flight height 300 m and battle-front 2.5 km putting 3-5 UAVs (in mountainous conditions) is real. In this case, all of them perform operational mission and return to base.

The offered method of application of the reconnaissance UAV possibilities allows to take into account correctly their significance and place in the informational support system, to reveal the nature and quantitative measures affecting on the efficiency of enemy targets detection system, and also to give the proof of priority and the importance of the fight against improvement of such targets. Based on this method the simulation and training UAVs war-game software for any mountainous conditions was developed[2,9].

4. CONCLUSIONS

The quantitative method of the assessment of invisible areas and military objects in mountain terrain by using UAF is presented in the paper. This method has been applied for quantitative assessment in selected mountain terrain of the Azerbaijan Republic. For calculations there have been used data early obtained by GIS technology. It has been established that for quantitative analysis of invisible areas it is more efficient to use one UAV, but for detection of armoured vehicles and military objects it is more efficiently to use several UAV. The probabilities of detection of the invisible areas and objects depend generally on the terrain relief and UAV speed.

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His contribution to the current study include : Quantitative assessment of invisible areas and military objects, modelling of UAV flights, and comparison data.

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His contribution to the current study include application GIS and photogrammetry technologies for research of invisible areas and military objects.