DETERMINATION OF COORDINATES OF TARGETS FROM UNMANNED AERIAL VEHICLES

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The article provides a mathematical solution to the problem of determining the coordinates of the target discovered during reconnaissance of the area by a reconnaissance drone.

Key words: *unmanned aerial vehicle, area reconnaissance, target coordinates, angle of direction, geographical coordinates, longitude, latitude.*

1. FOREWORD

The experience of wars and armed conflicts in recent years shows that modern combat operations have the following features: the use of unconventional forms of combat operations; increased accuracy and targeting capabilities of weapons used; giving greater priority to information warfare; the use of computer modelling, new control and reconnaissance systems. Based on these features, the general trend in the technological development of weapons and equipment is the use of artificial intelligence technologies, the miniaturization of weapons systems (reducing size and weight) and power consumption, increasing their versatility and autonomy, as well as simplifying their supply [1].

According to many military experts and foreign specialists, military unmanned (manned) systems and robotics will be the most promising types of weapons and military equipment combining the above areas [2]. It is expected that the large-scale application of artificial intelligence and robotics will change the methods of warfare and the technical characteristics of advanced weapon systems, increase their effectiveness and minimize personnel losses.

Analysis of the Second Karabakh War and a number of local armed conflicts shows that whenever the use of manned aircraft is impossible or inadvisable (strong enemy air defences, use of radiation, chemical and bacteriological weapons in the combat zone, as well as long-range enemy forces, etc.) the use of unmanned aerial vehicles (UAVs) for various tasks is assumed [3, 4].

Modern UAV complexes should perform the following tasks [2,5]:

1. Intelligence tasks:

- aerial reconnaissance (Figure 1);
- coordination of artillery fire;
- guiding high-precision weapons (target illumination);
- assessment of the impact of the attacks, etc.

2. Firing and impact tasks:

- elimination of ground, surface and air targets.

When performing these tasks, the UAV complex first of all conducts reconnaissance of the specified area, detects stationary or moving enemy objects, determines their coordinates or transmits images directly to the command post. When coordinating artillery fire or guiding high-precision weapon (target illumination), it is important to automatically determine target coordinates and promptly transmit them to the relevant ground points.

2. MATHEMATICAL ASPECTS OF DETERMINING TARGET COORDINATES

A military drone is an unmanned aerial vehicle is equipped with a video camera and a radio-rangefinder device. Considered that drone is equipped with device to determine the geographic coordinates and angle of the video camera and radio-rangefinder placed on board.

It is envisaged that the UAV will monitor (observe) terrain by hovering (without shifting) at a given altitude after detecting a target while performing a combat mission. In this case, after identifying the detected target, the UAV determines the distance to the target by means of a radio-rangefinder. In the process of surveillance, the targeting angles of the video camera (radar) can be

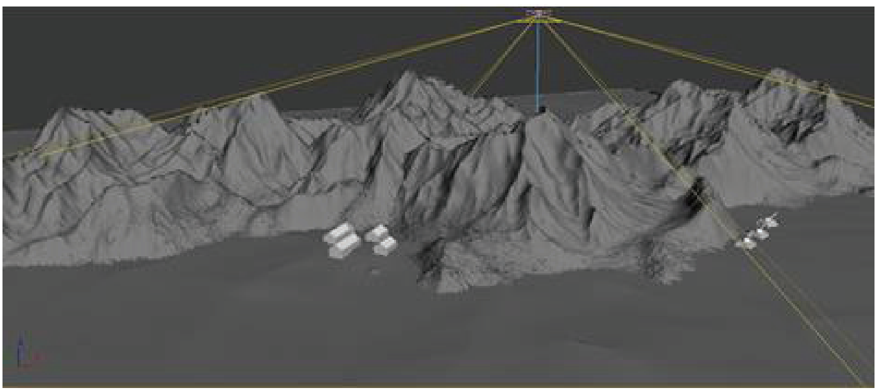

Fig. 1 Aerial reconnaissance by UAV

determined based on the data from the navigation devices on board the UAV. The main objective of the study is to develop a model for determining the geographic coordinates of the target based on this information.

problem, we introduce a rectangular coordinate system. *Oxyz* located at the point $O(U_G, E_G)$ on the Earth's central surface as follows (Figure 2). Assume that the *Ox* axis is oriented parallel to the eastward direction, the

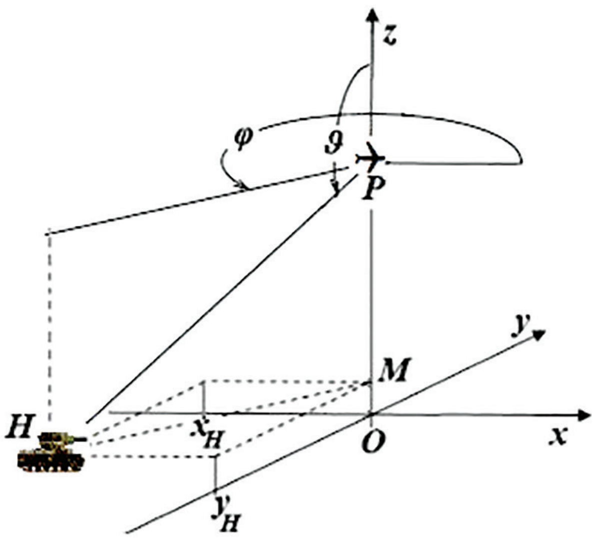

Fig. 2 Target coordinate diagram

2.1. Mathematical formulation of the problem

Let us denote the geographic coordinates of the UAV as U_G, E_G, where U_G, E_G are longitude and latitude, respectively. Since the military UAV observation area is very limited, the observed part of the surface can be considered flat. This allows the use of a rectangular coordinate system to simplify the calculations. To formulize the

Oy axis is oriented northward in the meridian direction, and the *Oxyz* axis is perpendicular to the axis plane.

The camera direction to the target is determined by the following two angles:

φ - the angle between the projection of the camera gaze direction onto the *Oxyz* plane and the *Ox* coordinate. This angle is considered positive when it is rotated clockwise and coincides with the axis;

ϑ - the angle formed by the viewing direction of the camera with the *Oz* axis. This angle is measured in all directions, starting from the positive direction of the *Oz* axis, and varies practically in the range $[\frac{\pi}{2}, \pi]$.

The point at which the UAV is in space relative to the *Oxyz* coordinate system is *P*, the point at which the target is located is *H*, and the distance between them is d = |PH|. According to the exercise, the distance *d* is calculated with the help of a radio-rangefinder mounted on board the UAV, and therefore it is assumed to be known. Based on the angles (φ,ϑ) representing the camera direction to the target, the position of the UAV and the target relative to the *Oxyz* coordinate system can be schematically described as shown in (Figure 1.) Thus, the solution to the problem in question is to find the geographic coordinates of point *H* by calculating the coordinates x H, y H with respect to the *Oxyz* coordinate system.

2.2. Solution of the problem

To calculate the coordinates of the rectangles x_H, y_H with respect to the *Oxyz* coordinate system, the known values of the angles (φ,ϑ) can be applied as follows:

$$HM = d \cdot \sin\vartheta;$$
$$x_H = |HM| \cdot \cos\varphi = d \cdot \sin\vartheta \cdot \cos\varphi;$$
$$y_H = |HM| \cdot \cos\varphi = d \cdot \sin\vartheta \cdot \sin\varphi.$$

As can be seen from (Figure 1), the longitude circle of point x_H, 0, 0 coincides with the longitude circle of point *H*, and the latitude circle is equal to E_G. Therefore, the calculated formulas for the longitude circle of point $(x_H,0,0)$are simplified. Similarly, we see that the latitude of point $(0,y_H,0)$ coincides with the latitude of point *H*, and the longitude circle equals to U_G. Therefore, the formulas for calculating the latitude of point $(0,y_H,0)$ are also simplified. To determine geographical coordinates of a point by calculated distances x_H and y_H one can apply, for example, Mercator projection formulas (6, p.44):

$$\begin{cases} X = R \cdot E, \\ Y = R \cdot \ln\left[\operatorname{tg}\left(\frac{\pi}{4} + \frac{U}{2}\right)\left(\frac{1 - \varepsilon \sin U}{1 - \varepsilon \sin U}\right)^{\frac{\varepsilon}{2}}\right], \\ \varepsilon = \sqrt{1 - \frac{r}{R}}. \end{cases} \qquad (1)$$

where *R* and *r* are the equatorial and polar (polar) radius of the Earth, respectively;

(E,U) and (X,Y) are the coordinates of the point in question in geographic and Mercator projection, respectively.

Applying formula 1 of system (1), we can calculate the circumference of point H with respect to point O as follows:

$$E_H = E_G + \frac{x_H}{R}. \tag{2}$$

Calculating the latitude of point H results in solving the following equation:

$$\mathrm{tg}\left(\frac{\pi}{4}+\frac{U_H}{2}\right)\left(\frac{1-\varepsilon\sin U_H}{1-\varepsilon\sin U_H}\right)^{\frac{\varepsilon}{2}} = \exp\left(\frac{y_H}{R}\right)\mathrm{tg}\left(\frac{\pi}{4}+\frac{U_G}{2}\right)\left(\frac{1-\varepsilon\sin U_G}{1-\varepsilon\sin U_G}\right)^{\frac{\varepsilon}{2}}. \tag{3}$$

Since equation (3) is non-linear with respect the unknown U_H, approximate calculation methods can be used to find its solution, e.g. the dichotomy method [7, p.39; 8, p.86].

Thus, formulas (1)- (3) can be applied to calculate the geographical (E_H, U_H) coordinates of the target based on UAV observation data.

3. CONCLUSION

In the Second Karabakh War, the use of UAVs as reconnaissance, firing and direct-attack missiles and artillery strikes changed military tactics and laid the foundation for a unique innovation in large-scale warfare. Thus, the combat tactics used by Azerbaijan Armed Forces engaging anti-aircraft missiles differed significantly from those used in local armed conflicts. This difference is evident in the scale of the war, in the combat capabilities of the opposing sides, and in the conduct of combat in mountainous areas and terrain that is difficult to traverse.

In mountainous terrain, with abrupt changes in terrain profile, it is difficult to determine the location of enemy forces and equipment, and there is uncertainty in information about the enemy. This creates problems when planning combat operations, determining firing points, conducting reconnaissance and detecting invisible enemy objects, and making last-minute decisions by commanders. In this regard, equipping reconnaissance and attack UAVs with appropriate computing devices would be a means of solving the aforementioned problems. The mathematical model for determining target coordinates from the aforementioned UAVs can be used in the design and production of military UAVs in Azerbaijan.

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