Concept Paper

Radio Holographic Method for UAV Detection and Recognition

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Abstract. The article proposes to use a radio holography for the detection and identification of unmanned aerial vehicles (UAVs).

Keywords: radio holography; UAV; antenna array; aperture synthesis; UAV identification

1. Introduction

The radar method for detecting UAVs [1] suffers from a number of disadvantages. These include the difficulty of distinguishing it from birds and determining the type of UAV. To overcome these difficulties, additional information channels are used - optical, infrared, acoustic, etc., which have a much shorter detection range for UAVs in comparison with the radar channel [2]. At the same time, the modification of the radar channel by supplementing it with the radio holographic method can immediately save it from a number of shortcomings. The radio holographic method for detecting and identifying UAVs will make it possible to visualize a drone without using other energy channels and without reducing the detection range, which reaches 12 km or more in the radar channel [1].

2. An overview of the application of radio holography in various disciplines

In [3], it is indicated that it is possible to measure the distance to artificial Earth satellites (AES) with an accuracy of up to 1 mm by radio or optical holographic method, which is important for creating geodetic networks, controlling the vertical movement of the earth's crust, and positioning unmanned aerial vehicles. To determine the range to an artificial satellite in existing non-holographic methods, a ground observation point (GOP) sends an optical (laser) or radio signal to the satellite, which is either reflected or re-emitted by the satellite. Based on the received signal on the GOP, taking into account the time delay, the Doppler frequency shift and the phase of the radio signal carrier, the relative speed of the satellite, the distance to the AES is determined with an accuracy of 1 cm to 1 m. In order to improve the measurement accuracy, the authors of [3] propose to use radio holography, which they only have in mind.

In [4], the Fraunhofer radio hologram reconstruction algorithm is considered. Fraunhofer radio hologram - the interference of a spherical reference wave with a plane wave diffracted by an object at distances to the object of size L and wavelength λ greater than $2L^2/\lambda$ [16]. Two point local sources are taken as an object. Numerical machine calculation is applied to the Kirchhoff-Fraunhofer integral, through which the reconstructed image is determined. It is noted that this method can be used for recognition of voluminous objects that are far away.

In [5], a radio holographic motion detector is considered, which allows determining the position of an object by tracking the change in the phase of the signal reflected from the object. A reference signal is a signal from stationary objects relative to which a searched object is moving. The signal reflected from the moving object and the signals from stationary objects are fed to the amplitude and phase comparators, which makes it possible to track an object that moves on arbitrarily trajectory, at any speed, even arbitrarily small, and even if it is stationary.

In [6], it is indicated that the increase in the resolution of the radio hologram occurs when the image is reconstructed using several frequencies (16 frequencies in the 1 GHz band with an operating frequency of 3 cm). In [7], 101 frequencies were used in the 800 MHz band with an operating wavelength of 8 mm. Formation of one frame no more than 0.4 sec.

In [8], [9], a radio holographic method for detecting (localizing) ore bodies with increased specific conductivity at a depth of up to 500 m in the earth's crust is described. The thickness of the ore body is up to several tens of meters. The source of the electromagnetic field is a horizontal square three-turn loop 50×50 m^2 with a current of 3 A, a current frequency of 136 Hz. The Kirchhoff integral was numerically solved by grid approximation with a step of 50 m from the surface to a depth of 500 m with a sector area of 350×400 m^2 for a magnetic field induced by magnetic currents in the ore body. In [9], it is noted that it is possible to improve the resolution of the localization of the ore body by using several frequencies, which will make it possible to cut off false images corresponding to the maxima of magnetic currents. The reference signal was taken from 1 meter of the loop. The magnetic field on the surface from inductive currents in the ore body was measured with a magnetometer.

In [10], a multifrequency method for reconstructing a holographic image of an object was applied using 21 frequencies uniformly distributed in the 4 GHz band with an initial frequency of 6 GHz. An antenna array was used with a pitch of 25 cm for the transmitting and 28.8 cm for the receiving array, respectively, and both arrays are located in the same plane. The number of elements is 81 for both antenna arrays. The radio image of two objects was restored - a sphere with a radius of 15 cm and a cube with a side of 30 cm. The centers of both objects were removed from the antenna plane by 2.3 m. The achieved resolution of the transverse dimensions of objects is 0.86λ, and the longitudinal dimensions – 0.94λ (λ=0.05 m). Narrowing the bandwidth resulted in a deterioration in resolution, while increasing the bandwidth slightly improved resolution. The Rayleigh limiting half-wavelength $\lambda/2$ resolution can be achieved with a simultaneous increase in the number of frequencies and bandwidth. The minimum distance between the elements of the antenna arrays should be about half the wave.

In [11], a scheme was proposed for obtaining a radio hologram using a 1×N transmitters line and a 1×N line of receivers perpendicular to it, which makes it possible to obtain a high-quality Fresnel radio hologram at a single frequency corresponding to λ = 1.3 cm. The distance to the object from the antenna is less than $2L^2/\lambda$ [16], where L is the size of the object.

In [12], an algorithm for restoring the radio image of an object with a hollow structure, irradiated by a radio wave and registering the reflected wave in the Fresnel zone, is proposed. No data on the equipment used and the formula of the algorithm are provided.

In [13], the antenna aperture synthesis method is noted as the fastest in obtaining a radio holographic image.

In [14], the application of the inverse Fourier transform to the Kirchhoff-Fresnel integral in radio holography of subsurface objects with anomalous permittivity is considered. In the experiment, we used two dipole antennas at a distance of 4 cm from each other and an Agilent E5071B vector analyzer, which made it possible to emit a probing signal at 801 frequencies in the range of 1.7–7 GHz and measure the complex amplitudes of the field scattered by inhomogeneities.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 November 2022 doi:10.20944/preprints202211.0379.v1

In [17], [18], a digital optical hologram was implemented on a CCD camera. The hologram was synthesized by numerically solving the Kirchhoff-Fresnel integral by the convolution method. This method can be taken into account, because the radio hologram is reconstructed in the optical range.

The [19] uses 16 microwave transmitters and receivers at 10.5 GHz, operating independently. Each receiver receives several reflected signals from neighboring transmitters. Distance to the object is 1 m (metal rod with a diameter of 1.5 cm). The mixed signal from each radar is amplified and converted to digital by an analog-to-digital converter and transmitted to a computer module. Using spectral analysis, the amplitude of the reflected wave is determined for each radar, and then a hologram of the object under study is synthesized.

3. Implementation of the UAV radio holographic detection channel scheme

We can propose the following scheme for the implementation of the radio holographic method of registration and identification of UAVs, shown in Fig.1. The carrier frequency signal of the remote radar before entering the antenna is split into two signals: one is fed through the phase shifter and attenuator *2* to the receiver, the second goes to the transmitting antenna *4*. The signal $\boldsymbol{e_{\Pi}}$ reflected from the drone and surrounding objects arrives at the receiving antenna array 3 with m×n elements, then into the input path. Each element of the antenna array has its own path, where the signal undergoes further processing - in 5 it is amplified, in 6 it is multiplied with the reference signal $\boldsymbol{e_{O}}$ delayed by the time of arrival of the reflected signal. A video pulse is formed in 7, the amplitude of which depends on the amplitude and phase of the signal at input of 7. Each element 7 at the output gives a video signal. Each of the **m×n** video signals is applied to a corresponding electrochromic display element; display has also **m×n** elements. An electrochromic element is a layer of glass above a layer of a transparent conductor made of indium-tin oxide (a video pulse is fed through it to the display element), then a layer of polymer-viologen (an electrochromic composite [15]). The latter changes transparency and color under the action of a video pulse from 7. Thus, an interference pattern is recorded on the display, which contains information about the phase and amplitude of the signal reflected from the object - a radio hologram. Irradiation of the display with laser 8 will lead to diffraction of optical radiation by electrochromic display elements located periodically and with different refractive indices in the radio hologram, which will give a reduced 3D image of an object on a flat screen in light reflected or transmitted through the screen.

Because for radio holography it is necessary to use the pulse mode of operation of the radar, then the transmitter 1 must be used on klystrons or traveling-wave tubes. The magnetron from pulse to pulse will give an arbitrary phase of the signal, which is difficult to take into account when forming a hologram.

The reduction in the image of a radio hologram, or compression ε, restored in the optical range, is equal to the following combination of values: $\varepsilon = \lambda \cdot r/(\Lambda \cdot r_{\phi})$ [16], where λ – wavelength of the radio signal (centimeter or millimeter range), r - object distance, Λ - laser wavelength, r_{ϕ} - focal length of the corrective lens between the hologram (screen) and the observer's eye in reflected or transmitted light (not shown in the Fig. 16). For an enlarged image, it is necessary that $\varepsilon < 1$.

 doi:10.20944/preprints202211.0379.v1

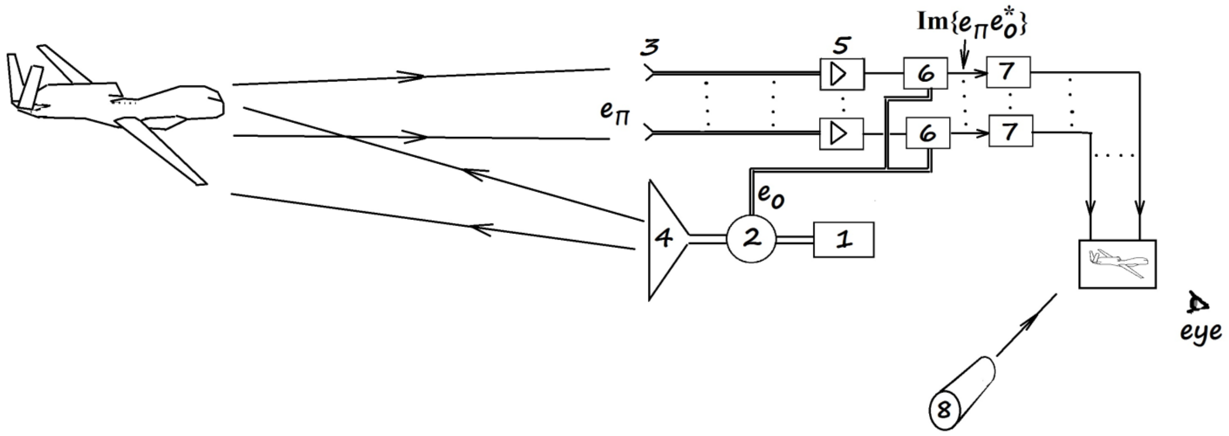

Fig.1. Scheme for the synthesis and restoration of a radio hologram of a drone: 1 – transmitter, 2 – phase shifter with attenuator, 3 – antenna array with dimension **m**×**n**, 4 – radiating antenna, 5 – **m**×**n** amplifiers, 6 - **m**×**n** multipliers, 7 – **m**×**n** low-pass filters, 8 – laser. $\mathrm{Im}\{e_\Pi e_O^*\}$ - discrete part of the hologram obtained from one element of the antenna array [16].

The screen for displaying the reconstructed radio hologram is described above as operating on electrochromic elements. Electrochromism is a phenomenon of a reversible change in the optical properties of a material (light transmission, color) placed between transparent conductive layers, to which an alternating voltage is applied. There are such electrochromic materials as metal oxide films, molecular dyes and conductive polymers. Electrochromes have independent contrast from the viewing angle, consume little power, require low control voltages, and are capable of storing an image. For an electrochromic device, the upper limit of transmission in the visible region of the spectrum reaches 70-50%, the transmission in a fully colored state is 25-10%. In [15], polymer electrochromics were developed in the form of a polymer-viologen complex, which have a high color switching rate, which is important for the formation of moving images.

There are three methods used together to increase the resolution of a radio hologram to identify a moving object: ***1)*** The use of interceptor drones (which will reduce r, and therefore reduce the compression ε), on which a transmitting antenna and a receiving antenna array are installed, and the received reflected signals are transmitted to a remote point via telemetry. ***2)*** The use of synthesizing the aperture of the antenna system of the stationary radar and on the interceptor drone, which will increase the resolution of the radio hologram image. ***3)*** Digital processing of the received reflected signals with the output of the restored digital radio hologram on the screen of a conventional display (allows the use of a large Λ, which will reduce the compression of ε).

4. Conclusion

The paper shows the fundamental possibility of implementing a radio holographic method for detecting and identifying UAVs, which has not been proposed so far. This method can provide reliable identification of drones without the use of additional information channels - optical, infrared, acoustic, etc. The next part of the work will contain an analysis of points 1-3) in subsequent articles.

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