

METHOD AND DEVICE FOR IDENTIFYING UNMANNED AERIAL VEHICLES AT LOW ALTITUDE

The invention relates to a method according to the preamble of the independent method claim and to a device according to the preamble of the independent device claim. In particular, the invention relates to the detection and location of micro-aircraft. The invention can be used to create technical means for protecting important ground objects according to the method of claim 1 [1].

The modern international situation is characterized by a new component that has confidently taken its place in military conflicts. These are drones. Drones play a significant role in reconnaissance, combat, defense, and attack. A large number of state- owned and private companies are involved in drone production. In practice, they are a new type of weapon. Defending against these weapons is a daunting task.

The real problem, however, is protection against micro-drones, as the absolute development trend is to minimize their size to a few centimeters. A related problem is that such micro-drones are less suitable for military conflict and more suitable for purposes of unprecedented terrorism.

Microdrones target cities and the people living in them. Swarms of microdrones won't fly into trenches to destroy soldiers, nor will they participate in field battles; they will fly into hotels, homes, offices, schools, and universities. If microdrones fell into the hands of terrorists, cities like Singapore or Dubai would quickly become impoverished because no one would protect their residents. And those against whom terrorism and blackmail are used will give everything for their children.

In the context of urban development—with the overwhelming amount of interference from reinforced concrete building structures, glass, mirrors, the entire urban infrastructure, various industries, and the life of the city itself—the task of detecting micro- drones is extremely difficult. Whatever the problem, the ultimate goal is the detection and identification of micro-drones measuring 1 to 3 cm in size in dense urban environments.

The detection process involves the use of various active and passive sensors. A feature of micro-drone detection in dense urban areas is a wide range of interference

and, at the same time, short distances to shielding obstacles, buildings, and structures. Of course, it's unlikely that traditional radar detection devices and lasers will be aimed at the windows of a neighboring hotel.

This results in the following requirement: active radar, acoustic and optical spatial detection in close proximity, which are required for reliable detection of micro-drones, must have a limited range in the form of physical boundaries (and must not be controlled by software). This requirement, on the one hand, enables a short detection range of the search object of up to approximately 100 m and, on the other hand, minimizes the influence of interference, including its own reflected acoustic signals.

This difficult requirement is to be implemented in the claimed invention by the use of active radar and acoustic sensors that operate in the range of resonant absorption of radio waves in the atmosphere (for a millimeter-wave radar sensor) and resonant scattering of acoustic waves on a micro-UAV (for an active acoustic sensor).

For example, since virtually all radar functions are performed in so-called "transparency windows," the operation of the vast majority of radio devices does not interfere with the radar detection proposed in the invention. At the same time, the task can be solved in opacity windows when detection does not require long distances, i.e., in full compliance with the requirement for detecting micro-drones in urban areas. Detecting micro-drones over long distances is not the intended goal. This is impossible in urban areas; micro-drones must be detected, possibly in open space "in front of the neighbor's house," usually no more than 100 meters.

At the same time, it is advisable to experimentally verify the required distances from the nearest urban objects for each specific (protected) object in order to optimize the solution to the problem of reliable detection of micro-drones and minimize interference from neighboring buildings and structures.

The use of radar systems for the detection of flying objects is well known. However, low-altitude unmanned aerial vehicles (UAVs) are a difficult target for existing radar systems. Low-altitude unmanned aerial vehicles have a small effective scattering area due to their small size (a few to tens of centimeters) and the use of low-reflectivity composite materials in their construction. In addition, active (radiating) radar stations are exposed to enemy electronic warfare systems. All of this reduces their

effectiveness due to the short range and low reliability of detecting low-altitude unmanned aerial vehicles in electronic warfare [2].

The closest approach to the claimed invention is a passive acoustic method for detecting or sensing unmanned aerial vehicles [3]. For example, the Ataka-Shoroh acoustic reconnaissance module is capable of detecting an approaching unmanned aerial vehicle at a distance of tens to hundreds of meters, depending on the level of external noise and the size of the drone's propellers.

The disadvantage of this method is its susceptibility to interference from external acoustic noise, or ambient noise for short. These effects reduce the detection range of unmanned aircraft. False positive results are also possible.

US 2015/0302858 A1 discloses the use of one or more microphones to record short sequences of acoustic noises and to decompose each of these sequences into its frequency spectrum. The frequency spectrum is compared with noise signatures stored in a database of various UAVs in different flight situations (hovering, ascent, descent, approach, departure) to identify a UAV. If a match is found, an alarm is triggered. The alarm can include information about the UAV model. The use of multiple microphones allows for directional detection of the UAV.

US 2021/0383665 A1 discloses a combination of acoustic and electro-optical detection for detecting UAVs. UAVs can be classified according to type and threat level. Acoustic sensors are arranged in a setup adapted to the terrain, terrain features, or man-made objects. A sound detected by one or more of the acoustic sensors is compared with known sound signatures to classify the source of the sound. The sound signatures contain information specific to UAVs. Acoustic detection can be combined with optical imaging, optical video, thermal imaging, electro-optical infrared, radio frequency detection, RADAR, LIDAR, and full-spectrum electromagnetic radiation detection, including any combination thereof, for example, to display a video image or a 3D visualization of a field of view in which non-line-of-sight acoustic detection indicates a UAV as the noise source.

The technical task of the invention is to increase the reliability of detection and to enlarge the detection range of unmanned micro-aircraft with rotating propellers (engines) at low altitude in the presence of external noise.

In particular, it is an object of the invention to increase the detection efficiency of low-altitude micro-UAVs in urban areas by increasing the reliability of detection and the secrecy of operation in the event of external interference.

The problem is solved both by the features of the independent method claim and by the features of the independent device claim.

It can be seen that the invention can be implemented as follows. To detect low-altitude micro-drones (UAVs), their acoustic signals caused by mechanical vibrations of their electric motors and the rotation of their propellers are recorded. At the same time, the occurrence of a parametric modulation of the optical signal caused by the same mechanical vibrations is recorded in both the visible ($0.4 \text{ } 0.76 \text{ }\mu\text{m}$) and infrared ($0.76 \text{ }\mu\text{m} \dots 1 \text{ mm}$) ranges of the waves reflected from the UAV, while the correlation between these two low-frequency signals is recorded (the presence of which indicates the detection of a UAV).

The detection of a flying object is carried out by using at least two independent search channels (sensors):

- at least one passive optical channel using the visible wavelengths (e.g. $0.4 \dots 0.76$ micrometers), and/or
- at least one passive optical channel using infrared wavelengths (e.g. 0.76 micrometers 1 mm),
- at least one passive acoustic channel that uses the frequency range perceptible to the human ear (e.g. $10 \text{ Hz} \dots 20 \text{ kHz}$) and, where appropriate, adjacent frequency ranges (e.g. $3 \text{ Hz} \dots 10 \text{ Hz}$; $20 \text{ kHz} \dots 30 \text{ kHz}$), and, if necessary, additionally
- at least one active radar channel in the millimeter wavelength range, in short millimeter detection range, and/or
- at least one active acoustic channel,

for example by using three search channels (sensors).

Active acoustic channels operating at the wavelength of resonance scattering of acoustic waves on unmanned aerial vehicles are preferably included in the detection process; active radar channels of the millimeter detection range, whose wavelength coincides with the wavelength of resonance absorption of the signal in the atmosphere, are preferably included in the detection process.

It is apparent that to achieve the object underlying the invention, it may be provided to use active radar and acoustic sensors operating in the windows of resonance absorption (for a millimeter-wave radar sensor) and resonance scattering of sound waves on a micro-UAV for an active acoustic sensor, as well as optical sensors operating in the visible and IR range.

The wavelength of resonance absorption in the atmosphere was taken from reference data on the propagation of radio waves in various media (gases, liquids, solids, etc.) from known literature sources.

The aforementioned passive optical sensor works together with a passive acoustic sensor.

It is known that, under favorable conditions, a modern passive optical sensor is capable of detecting a low-altitude unmanned micro-aerial vehicle at a distance of 500 meters during the day [4]. At night, the detection range with an infrared thermal imaging camera is tens or even hundreds of meters [2]. However, the use of only one optical channel makes the detection process unstable.

Particularly in the passive detection channels, the passive optical and the passive acoustic, and preferably in both detection channels (acoustic and optical), low-frequency modulation components are recorded. These are caused by the mechanical oscillations or vibrations of electric motors and rotating propellers of low-flying UAVs. At the same time, there is a fixed and stable correlation between the two components. The coincidence of the low frequencies is due to the number of revolutions of the rotating propellers, which generate a low-frequency parametric "spiral" modulation of the optical signal [5]. The use of correlation significantly increases the range and noise

immunity of the detection method. Low frequency can refer to changes in a signal in a range of 20 Hz to 20 kHz.

The claimed method additionally includes an active millimeter-wave radar sensor whose wavelength preferably matches the wavelength of resonance absorption of the signal in the atmosphere (1...15 mm) at a given altitude range of unmanned aerial vehicles. Millimeter-wave radio waves experience the greatest attenuation in the atmosphere. This is due to absorption lines in the millimeter range caused by the oxygen and water vapor molecules present in the atmosphere. The absorption process is due to resonant quantum mechanical effects.

The water vapor molecule has a constant electric moment, whose interaction with the electromagnetic field causes the resonance absorption of radio waves. Maximum absorption occurs in the range of 10 to 15 mm, as well as at wavelengths shorter than 3 mm.

The oxygen molecule contained in the atmosphere has a magnetic dipole moment that causes the appearance of a single absorption line at a wavelength of 2.5 mm and a line complex (burst) at 5 mm.

The use of wavelengths with resonance absorption in the atmosphere (attenuation coefficient reaching 20...30 dB/km or more) of the active radar channel (radar sensor) increases the secrecy of the radar sensor's operation [7]. Furthermore, at these millimeter-range wavelengths, the degree of interference is significantly lower, as they are rarely used in various electronic systems. The radar sensor registers the reflected microwave signals only at a specific altitude range of the unmanned aerial vehicle, i.e., at short intervals (a few tens of meters). This avoids interference from large flying objects (aircraft, helicopters) located at great distances.

Preferably, an active acoustic sensor is also included, operating at wavelengths at which acoustic waves are scattered by unmanned aerial vehicles due to resonance. [8] Since the minimum dimensions (micro) are specified in centimeter units, the wavelengths of the acoustic field must correspond to these to ensure resonance

scattering. Given the speed of sound in air (approximately 340 m/s), this corresponds to frequencies of several tens of kHz. Accordingly, the optimal frequency range of an active acoustic sensor for distances up to 50 meters is 10...20 kHz. In this case, the attenuation coefficient is an acceptable value of 0.2 - 0.8 dB/m. The total loss over a distance of 100 meters is only 20-80 dB, which is within acceptable limits for an acoustic sensor. At the same time, the value of the acoustic sounding signal at a distance of 100 meters or more will be insignificant, which makes it difficult for the "enemy" to register it.

How a resonance scattering signal can be calculated is well known to the person skilled in the art.

Similar to classical radar, the effective scattering area of objects (micro drones, UAVs) in acoustics has 3 characteristic wave scattering areas:

- Rayleigh, when the wavelength is much larger (at least 2-3 times) than the characteristic size of the object;
- Resonant if the wavelength corresponds to the size of the object (in our case);
- Quasi-optical, when the wavelength of the acoustic field is much smaller (at least 2-3 times) than the characteristic size of the object.

Calculating the reflection properties of real drones with complex shapes is challenging. Therefore, an approximation is used that can also be implemented according to the invention. However, these are preparatory steps that do not necessarily occur during the inventive detection method, but can be taken from a precoded database for the range of various flying objects of different sizes and/or shapes.

When evaluating drones, it is possible to replace the drones with a sphere whose diameter corresponds to the length of the drone's fuselage. In this case, the value of the acoustically effective scattering area ("force target") is close to the value of the transverse scattering area of the sphere. The characteristic resonance deviations of the sphere's reflection properties are no less than 35 dB. For an object diameter of,

for example, 3 cm (micro-drone), the resonant scattering range (wavelength of approximately 3 cm) is in the range of 10 kHz.

Of the three typical characteristic ranges of sound wave scattering, in our case there is preferably a resonance range in which the wavelength corresponds to the size of the object, i.e. in which the reflection is maximum.

Since we also prefer to consider the detection of micro-drones with a size of 3 centimeters, the wavelength will also be approximately 3 centimeters. The corresponding frequency, according to the formula:

$F \text{ (Hz)} = V \text{ (sound)} / \lambda \text{ (wavelength)} = 340 \text{ (m/s)} / 3 \times 10^{-2} \text{ (m)} \approx 11 \text{ (kHz)}$, and is in the range 10 ... 20 (kHz).

For example, if a 2 cm micro-drone is to be detected, the length of the acoustic wave corresponding to the characteristic resonance scattering is also approximately 2 cm, or the frequency ≈ 17 kHz. A scanning process can be performed in which the frequencies are changed until the correct frequency for the correct micro-drone is identified through the corresponding detection of the resonance scattering.

The preferred simultaneous use of four sensors with optimal signal processing (correlation for the first two sensors) and a common coincidence circuit for all four sensors makes it possible to increase the reliability of detecting unmanned aerial vehicles under the influence of acoustic, optical and electromagnetic microwave interference.

In order to camouflage, hide or conceal an execution of the method or an operation of a device executing the method, which is also referred to in this document as a secret or secrecy of operation, in particular from external detection and to reduce energy consumption, the active radar and acoustic detection takes place when the control signal of an additional passive acoustic channel is switched on, which operates in standby mode..

To test the performance of the most complex component of the proposed method, a field experiment was conducted. The object of the experiment was a small MJX Bugs

3 quadcopter equipped with low-noise brushless propellers. It weighed 447 grams and had overall dimensions of 44 x 44 x 15 centimeters. The quadcopter was mounted on a tripod 15 meters away from the Shure SM58 microphone and the optical sensor. The optical sensor used was a 12x monocular with an FD-7k silicon photodiode mounted on a vibration-resistant tripod. The photodiode was loaded onto a broadband low-frequency matching amplifier. The photodiode operated in the visible and near-infrared range ($\lambda_p = 0.4 \text{ } 1.1 \text{ } \mu\text{m}$).

The low-frequency spectrum of the microphone and the optical sensor was recorded using an S-48 spectrum analyzer. Operating mode: "narrowband," bandwidth: 5 Hz.

During the measurements, the rotation frequency of the quadcopter's two-blade propellers varied from 6000 to 9000 rpm. In this case, a low-frequency spectrum was recorded (fundamental frequency F and its harmonics), which was in the frequency band from 200 Hz and higher, which corresponds to the known dependence [6]:

$$F = \frac{\omega N}{60}, \text{ Hz},$$

where ω is the propeller speed,
rpm,

N - Number of sheets.

It has been experimentally established that the components of the spectrum of the acoustic signal and the low-frequency signal at the output of the optical sensor match with an accuracy of 3-5%. This allows the detection of signals from low-altitude unmanned aircraft and micro-aircraft against the background of acoustic noise – using a correlator.

Fig. 1 shows a block diagram of a device (1) that implements the proposed method for detecting unmanned micro-aircraft at low altitude.

The device for detecting unmanned micro-aircraft in low-level flight can comprise a passive acoustic sensor (2), a passive optical sensor (receiver of modulated optical radiation in the visible and infrared range (4), a correlometer (3), preferably an active acoustic sensor (5), preferably an active radar sensor (6). Preferably, a coincidence circuit (with actuator) (7) is included. The correlometer (3) is intended to detect the correlation relationship of signals from the outputs of passive acoustic and optical sensors.

The device (1) for detecting unmanned micro-aircraft at low altitude functions as follows, according to a non-limiting embodiment. An acoustic signal from an unmanned micro-aircraft at low altitude is received by a passive acoustic sensor (2). In this case, a modulated optical signal from an unmanned aerial vehicle is simultaneously recorded with an optical sensor (4). Low-frequency signals from the outputs of the two sensors are fed to the inputs of the correlometer (3). Their spectra match because they are generated by the same rotating propellers. In this case, the signal is fed into the coincidence circuit (7), and the signals from the two active sensors, acoustic (5) and radar (6), also enter the coincidence circuit. The actuator can then be triggered. The actuator is preferably understood as an addition to the detection method according to the invention and is not required for the detection itself.

It is important to note that the invention comprises a method for detecting unmanned micro-aircraft (UAVs) at low altitude, including recording their acoustic signals caused by mechanical vibrations of electric motors and the rotation of propellers, which method is characterized in that:

- In addition, an optical signal is recorded in the visible ($0.4 \dots 0.76 \mu\text{m}$) and/or infrared ($0.76 \mu\text{m} \dots 1 \text{ mm}$) range of the UAVs,
- the occurrence of a parametric modulation of the optical signal caused by these same mechanical vibrations is detected,

whereby a correlation of acoustic and optical signals of the UAV is registered, the presence of which indicates the detection of the UAV.

The correlation can be carried out in a (low) frequency range caused by the mechanical vibrations of electric motors and the rotation of propellers of UAVs.

The invention therefore proposes the correlation of two low-frequency harmonic signals based on a known, well-developed mathematical apparatus containing a simple, specific formula for the correlation coefficient. The term "low-frequency" refers to a frequency range encompassing mechanical vibrations of UAV electric motors and caused by the rotation of their propellers. For this purpose, a direct mathematical expression can be used that describes the specific physics of the process without the use of complex statistical methods. This helps to create technical samples with better sensitivity and selectivity, which is a clear advantage.

In addition, the method may provide for active radar detection in the millimeter range, the wavelength of which corresponds to the wavelength of a resonance absorption in the atmosphere reflected by the surface of the drone (micro UAV electromagnetic waves), preferably in the range of 1 mm to 15 mm, particularly preferably within a given (flight) altitude range of drones, preferably between 5 m and 50 m.

The peculiarity of this design is that active radar detection is performed with respect to micro-drones measuring 1 to 3 cm in urban areas. Based on this requirement, an active radar sensor must scan the space at a distance of preferably up to 100 m, while the probing signal must be significantly weakened at greater distances to prevent the reflected signal from surrounding buildings and structures from interfering with the radar receiver sensor. Another important purpose of this attenuation, which exceeds the distance to a given detection line (approximately 100 m), is to achieve additional secrecy of the probing signal from the "enemy." As a method (claim 2) for solving the problem, the claimed invention proposed active radar detection in the millimeter range, whose wavelength coincides with the range of resonant absorption of radio waves in the atmosphere reflected from the surface of micro-UAVs (in the range of 1 mm to 15 mm). The masking properties of the atmosphere for the sounding signal in this radio wave range are most suitable in our case. This is due to the presence of absorption lines of oxygen molecules and water vapor in the atmosphere in the

millimeter range. The absorption process is caused by resonant quantum mechanical effects. The use of resonant absorption wavelengths in the atmosphere (the attenuation coefficient reaches 20-30 dB/km or more) increases the secrecy of the radar sensor. In addition, interference levels at these millimeter wavelengths are significantly reduced, as they are rarely used in various electronic systems. The radar sensor detects reflected microwave signals only within a certain altitude range of the unmanned aerial vehicle, i.e., at short distances (tens of meters). This eliminates interference from large flying objects (aircraft, helicopters) at great distances.

The resulting advantages are minimizing interference and increasing secrecy when implementing active radar detection of micro-drones with a size of 1...3 cm in dense urban areas.

An advantageous embodiment of the method can provide that it additionally comprises an active acoustic detection which operates at a wavelength of the resonance scattering of acoustic waves on unmanned aerial vehicles in the frequency range of 10 kHz...20 kHz.

Since the minimum dimensions of UAVs, also known as micro-drones, are a few centimeters, the wavelengths of the sound field must match these to ensure resonant scattering. Considering the speed of sound in air (approximately 340 m/s), this corresponds to frequencies of several tens of kHz. Accordingly, the optimal frequency range of an active acoustic sensor at distances of up to 100 meters is 10–20 kHz. In this case, the attenuation coefficient has an acceptable value of 0.2–0.8 dB/m. The total loss over a distance of 100 meters is between 20 and 80 dB, which is within acceptable limits for an active acoustic sensor.

The advantage is that it can significantly reduce all types of interference in urban environments. At the same time, the strength of the acoustic probing signal is negligible at a distance of 100 meters or more, making it difficult for the "enemy" to detect it.

In this case, the effective detection of micro-drones does not exceed several dozen meters, while "picking up" a minimal amount of acoustic interference and remaining hidden from the "enemy." This is certainly a significant advantage for the specific requirements for active acoustic detection of micro-drones measuring 1 to 3 cm at a distance of up to 100 m in a given UAV altitude range, preferably from 5 m to 50 m.

It is also important to emphasize that the invention alternatively or additionally comprises a device (1) for detecting UAVs in low-level flight. The device (1) comprises:

- a passive acoustic sensor (2),
- a passive optical sensor (4), and
- a correlometer (3).

The correlometer (3) is advantageously used to correlate acoustic and optical signals with respect to a parametric modulation caused by mechanical vibrations of electric motors and the rotation of propellers of a UAV, the presence of which indicates the detection of a UAV.

The device (1) allows the execution of a method implementing the invention.

Furthermore, the device (1) may comprise an active acoustic sensor (5) which is set to operate at a wavelength of resonance scattering of acoustic waves on unmanned aircraft in the frequency range of 10...20 kHz.

Alternatively or additionally, the device may comprise an active radar sensor (7). The active radar sensor (7) is advantageously adjusted to operate at a wavelength that corresponds to a resonance absorption of the signal in the atmosphere in the range (1 mm...15 mm). The active radar sensor detects UAVs at flight altitudes of 5 m...50 m.

The device (1) may further comprise a coincidence circuit (7) whose three inputs are connected to the outputs of the correlometer and the active acoustic sensor (5) and the radar sensor (6).

Advantageously, the passive acoustic sensor is selected as a broadband sensor with increased sensitivity, preferably operating in standby mode. When it receives a signal, presumably from a micro-UAV, it can control the activation of active radar and acoustic sensors.

At the same time, by exploiting the absorbing (camouflaging or masking) properties of the atmosphere in the optimal range of radio and acoustic wavelengths, preferably using pulse or FM modulation, active sensors create a detection zone for micro-drones in the form of a "safety envelope" covering an object (which may be the target of micro-drone attacks), as they have a fixed, limited detection range – preferably up to 100 m – while being subject to minimal interference and providing additional secrecy for active acoustic and radar sensors (in urban areas).

For the device, active radar and acoustic sensors are advantageously selected. These operate in the optimal range of radio and acoustic wavelengths, exploiting the absorbing (camouflaging or masking) properties of the atmosphere, preferably using pulse or FM modulation. They create a detection zone for micro-drones in the form of a "radio-acoustic containment envelope" with specific physical and geometric properties that covers an object (which may be the target of a micro-drone attack), as they have a certain limited detection range—preferably up to 100 m at a certain altitude range of 5 to 50 m.

Preferably, it can be provided that the acoustic signal of the unmanned micro-aircraft is received at low altitude by the passive acoustic sensor (2), wherein, preferably simultaneously, the modulated optical signal of the unmanned aircraft is detected by the optical sensor (4).

Preferably, the low-frequency signals from the outputs of both sensors are fed to the inputs of the correlometer (3), whereby the signal from the output of the correlometer

(7) can be fed to the input of the coincidence fixing circuit (7). Optionally, preferably simultaneously, other inputs of the coincidence fixing circuit (7) can be supplied with signals from the active acoustic sensor (5) and the radar sensor (6). (Fig. 2)

At the same time, they are subject to minimal radar and acoustic interference and provide additional secrecy of sources of sounding signals in dense urban areas – which is a clear advantage over devices (device elements) for detecting UAVs at the presented technology levels.

It is important to emphasize that the invention provides for a correlation of two low-frequency harmonic signals. This can include pattern recognition in a (low-) frequency range caused by mechanical vibrations of electric motors and the rotation of UAV propellers, both in an acoustic and an optical range, for example, the range of the electromagnetic spectrum visible to the human eye, and/or in the infrared range. Alternatively or additionally, a radar signal, for example, a radar signal in the millimeter wavelength range, can be analyzed for such a (low-) frequency range caused by mechanical vibrations of electric motors and the rotation of UAV propellers in order to increase the detection reliability of UAVs.

It is important to emphasize that the invention is suitable for detecting so-called micro-drones. The dimensions of the micro-drone as a search object are 1...3 cm.

Advantageously, the detection is subject to detection limitations - distance up to 100 m, range of specified heights 5...50 m.

Advantageously, the active radar detection wavelength is between 1 mm...15 mm, corresponding to the range of resonant absorption of radio waves in the atmosphere.

The frequency range of active acoustic detection (working at the wavelength of resonant scattering of sound waves in the atmosphere) is advantageously between 10 kHz...20 kHz.

Advantages of the invention include the secrecy of the sources of sounding signals, along with the creation of a radio-acoustic security envelope. These are tactical and

technical features that offer unparalleled advantages when using active radar and acoustic sensors to detect micro-drones.

Device (1) can utilize active radar and acoustic sensors that operate in the optimal range of radio and acoustic wavelengths, exploiting the absorbing (masking) properties of the atmosphere, preferably using pulse or FM modulation. They create a detection zone for micro-drones in the form of a "radioacoustic containment envelope" with defined physical and geometric properties that covers an object (which may be the target of a micro-drone attack), as they have a fixed, limited detection range— preferably up to 100 m in a specified altitude range of 5 to 50 m.

At the same time, they are minimally exposed to radar and acoustic interference and provide additional secrecy of sources of probing signals in dense urban areas – which is a clear advantage over UAV detection devices (elements) at the presented technology level.

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CLAIMS

1. Method for detecting unmanned micro-aircraft (UAV) at low altitude, including recording their acoustic signals caused by mechanical vibrations of electric motors and the rotation of propellers, characterized in that
 - In addition, an optical signal is recorded in the visible (0.4 ... 0.76 μm) and/or infrared (0.76 μm ... 1 mm) range of the UAVs,
 - the occurrence of a parametric modulation of the optical signal caused by these same mechanical vibrations is detectedwhereby a correlation of acoustic and optical signals of the UAV is registered, the presence of which indicates the detection of the UAV.
2. Method according to claim 1, characterized in that the correlation takes place in a (low) frequency range caused by the mechanical vibrations of electric motors and the rotation of propellers of UAVs.
3. Method according to claim 1 or 2, characterized in that additionally an active radar detection in the millimeter range is provided, the wavelength of which corresponds to the wavelength of a resonance absorption in the atmosphere, preferably in the range of 1 mm to 15 mm, within a given (flight) altitude range of drones, preferably between 5 m and 50 m.
4. Method according to claim 1, 2 or 3, characterized in that it additionally comprises an active acoustic detection which operates at a wavelength of resonance scattering of acoustic waves on unmanned aerial vehicles in the frequency range of 10 kHz...20 kHz.
5. Method according to claims 1, 2 or 3, characterized in that the acoustic signal of the drone is received at low altitude by the passive acoustic sensor (2), preferably simultaneously with the modulated optical signal of the drone via the optical sensor (4), wherein the low-frequency signals from the outputs of both sensors are preferably fed to the inputs of the correlometer (3), wherein the signal from the output of the correlometer (7) can be fed to the input of the coincidence fixing circuit (7) and additionally, preferably simultaneously,

signals from the active acoustic sensor (5) and from the radar sensor (6) are fed to the other inputs of the coincidence fixing circuit (7).

6. Device (1) for detecting unmanned micro-aircraft (UAV) in low-level flight, comprising
 - a passive acoustic sensor (2),
 - a passive optical sensor (4), and
 - a correlometer (3), and
 - an active acoustic sensor (5) adjusted to operate at a wavelength of resonance scattering of acoustic waves on UAVs in the frequency range of 10...20 kHz, and
 - an active radar sensor (6) operating at a wavelength that matches the wavelength of resonance absorption of the signal in the atmosphere in the range (1 mm...15 mm) and detects UAVs at flight altitudes of 5 m...50 m.
7. Device according to claim 6, which includes a coincidence circuit (7) whose three inputs are connected to the outputs of the correlometer and the active acoustic and radar sensors.