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SPECIAL FEATURES OF THE PASSIVE AND ACTIVE RADAR SYSTEMS MULTIPLEXING

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Abstract—*This paper deals with the unmanned aerial vehicles detection, identification and coordinates calculation approaches that can be used in the complex systems "passive radar-altimeter" and "passive radar-active radar". The mathematical apparatus of the task solution in the redundancy conditions on the quadratic functional minimization basis is taken into account, justification of the considered method of the coordinates determination is given. Imitating modeling of the coordinates determination is executed.*

Index Terms—Passive radiolocation complex; detection; identification; coordinates calculation,quadratic functional; redundant information.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are now actively used for the prospecting purposes, targeting, statement of hindrances, in systems of remote control and supervision, systems of air relaying, as shock means, etc. In this regard there is an important scientific and practical problem of detection of the UAV and determination of its coordinates [1].

Detection complexity of the UAV is connected with their small overall dimensions, properties of materials of which the UAV case is manufactured, and also that UAVs possess high manoeuvrability [2].

Now for detection of the UAV are used both means active, and passive radar-location. Active means of the radar-location possess quite high precision, however, can be easily found and then put out of action. At the same time, passive means of the radar-location though possess much lower accuracy of the UAVs coordinates definition, however, have reserve of work and can't be found by traditional means of the radar-location [3], [4].

II. DETECTION PROBLEM STATEMENT

Thus, having a complex of the passive, and three-coordinate active radars, and considering work features of the both system types, there is a problem of their shared use for the strengths use of each of the systems for UAVs detection and coordinates determination [5], [6].

III. DETECTION AND IDENTIFICATION METHODS, TECHNICAL MEANS COMPLEXES REVIEW

For the solution of this problem the whole complex of methods and technical solutions on the basis of various principles of receiving and information processing in radio frequency range of the electromagnetic waves was offered. From the most effective ways of UAVs detection it is possible to give the following:

– the way consists in radiation in space by means of radar station of the pulse probing signals, their reflection from the UAV, reception of the reflected signals by antenna system of the radar, filtration of the reflected signals on frequency for allocation of reflections from moving air objects against reflections from motionless local subjects, comparison of the filtered reflections with a threshold and in case of excess of the established threshold – decision-making that the moving UAV is found [7];

– use of two-frequency pulse radars. The first group of frequencies is in the decimetre range, the second in the centimetre for UAV detection. For increase of the system reserve it is possibly to use of the rather low-power monopulse locators. With the sending length more than 8 periods of the microwave fluctuations phased array is actual. Application of the special methods allows to use the phased array at the shorter sendings [8];

– all frequencies range viewing (search for all waves lengths values, commensurable with UAV sizes and design elements), and detection accuracy increase. The specified result is reached by the choosing of the sounding basic initial frequency equal to 150 MHz, and the frequency tuning up to 6 GHz. After the analysis of reflections at various frequencies and identification of the fact of emergence of the spectral response exceeding the threshold on one of frequencies radiation is changed from the mode with the frequency tuning to the single-frequency mode corresponding on frequency to existence of the spectral response from the hardly noticeable UAV [8];

– way based on Fourier's transformation with the subsequent analysis of the spectral array, in which at the UAV presence at the distance, corresponding to the used distance strobe the spectral response will be created, which frequency position corresponds to the Doppler frequency of the signal reflected by this UAV, and then the spectral responses of the reflected signals are compared to the threshold value. In case of excess by the spectral response of the threshold, the frequency of this spectral response is fixed as the frequency of its maximum component, and then the decision is made about the UAV existence at the corresponding distance [8].

For the analysis and identification of UAVs types can be used frequency, temporary and time-and-frequency characteristics of signals.

Are among frequency parameters:

– radiated fluctuations frequencies values;

– ranges borders and their change by tuning;

– frequencies values by discrete tuning;

– impulses following frequencies;

– impulses following frequencies values at discrete tuning.

Are among temporary parameters:

– radio emission character (continuous or pulse);

– impulses duration;

– impulses duration value by discrete tuning.

Treat time-and-frequency parameters:

– frequency change character in time (invariable, changing from an impulse to an impulse, changing within an impulse);

– instant frequency change character within an impulse (linear, spasmodic, pseudorandom, random);

– impulse following frequency change character (invariable, changing in the set way, changing in the random way).

The analysis of standard UAVs-radars allows to draw the general conclusions that by development of the requirements to information and measuring systems of the standard objects identification by parameters of radio emissions it is necessary to consider the following.

1. Radars can be sources of both pulse, and continuous radiation, and both frequency, and temporary parameters of radiation can change under the complex, including random law. The specified circumstance doesn't allow to process such signals by means of the approaches applicable to stationary processes. In particular, the processing methods using hypotheses of stationarity and ergodicity are excluded.

2. Not stationarity of the signals displaying radio emission causes the need of estimation of their informative parameters during the whole time of supervision of the radiation sources. Reduction of this time or use for such estimates of limited temporary segments of signals can significantly reduce their informational content that will cause deterioration of reliability of identification. This circumstance indicates the need of the full-size realization processing of the signals displaying the radio emission, with the help of the means of receiving dynamic spectral estimates in real time.

3. Complex character of change and not stationarity of the probing signals displaying the way of change in time of the radar signals cause need of use of consecutive procedure of their analysis for information and measuring system, beginning from detection of a radio emission in some, rather wide range, the subsequent specification of parameters of a radio emission in the supervision process, receiving estimates of parameters by supervision results on rather extended (but not allowing the data relevance loss) time interval, and, at last, radiation sources identification on this basis.

4. In view of the fact that ranges of possible values of the same name, informative parameters of radio emissions for various radars can be covered, unambiguous identification in one parameter (for example, frequency) is impossible. Identification reliability increase requires complex use of the maximum quantity of the informative parameters characterizing current state of the radio emission source in the UAV-identification time conditions limited from above.

In certain cases information for UAV-identification can be received by results of comparison of frequency ranges of the parcels following one after another therefore it is necessary to provide means for the comparative analysis of the next parcels in information and measuring system.

As the frequency parcels formed by UAV-transmitters are narrow-band signals, changes in thin structure of their current ranges can be hard to distinguish visually without use of special means of the analysis and visualization therefore it is expedient to provide:

– continuous frequency analysis of the current spectrum developed in signal time with detection of change sites of its main (central) frequency;

– allocation of sites of the current spectrum where the abnormal time-and-frequency phenomena take place (changes of the main frequency of a signal in the continuous way, jumps of frequency, etc.);

– time-and-frequency magnifying glass mode for detailed studying of the way of the spectrum change on the allocated sites;

– markers system for sites allocation with the abnormal time-and-frequency phenomena, and also means for determination of their extent on the temporary and frequency axis [10].

As passive system can be used “Kolchuga-M” – passive radar-location complex consisting of four stations which is capable to determine coordinates of air targets. Radio path sensitivity of the passive complex makes from 110 to 155 dB/W in the panoramic review band. It is provided with five antenna systems calculated for the different wavelengths.

“Kolchuga-M” controls pulse and continuous radiation at frequencies of 135–170, 230–470 and 750–18000 MHz. The system is equipped with the parallel 36-channel detection receiver and the electronics capable to exclude background signals and at the same time to follow the signals from many targets.

As the active mean is used the three-coordinate active radar or the altimeter having the operation possibility in the different frequency ranges.

IV. COMPLEX SCHEMATIC STRUCTURE

The system “complex of passive radiolocation – altimeter” or “complex of passive radiolocation – three-coordinate active radar ” consists of four spaced stations *C*, *R*, *L* and *Q* and the altimeter (three-coordinate active radar) *S* (Fig. 1).

IV. UAV COORDINATES DETERMINATION SYSTEM ALGORITHMIC SUPPORT

The coordinates determination algorithm flowchart will consist of passive and the active component (Fig. 2).

Accept signal arrival time delays at the passive complex station: $\tau_1=\tau_L$, $\tau_2=\tau_Q$, $\tau_3=\tau_R$, $\vec{\tau}=[\tau_1,\tau_2,\tau_3]$, $\vec{x}=[x_1,x_2,x_3]$. The quadratic functional estimating value of the aggregate error of the system consisting of the passive radiolocation complex and the altimeter can be written as:

$$J(x_1,x_2,x_3)=$$
$$\sum_{j=1}^{3}\Big[\Big(\sqrt{\left(x_1-x_1^j\right)^2+\left(x_2-x_2^j\right)^2+\left(x_3-x_3^j\right)^2}$$
$$+D_j-\sqrt{x_1^2+x_2^2+x_3^2}-\tau_j c\Big)\Big]^2+\left(x_3-h\right)^2,$$

where x_1^j,x_2^j,x_3^j are the stations corresponding coordinates; h is the UAV-height measured by the radio altimeter.

In turn, the quadratic functional estimating value of the aggregate error of the system consisting of the passive radiolocation complex and three-coordinate radar can be written as:

$$J(x_1,x_2,x_3)=\sum_{j=1}^{3}\left(F_j^2+\tilde{D}_j^2\right);$$

$$F_j=\sqrt{(x_1-x_1^j)^2+(x_2-x_2^j)^2+\left(x_3-x_3^j\right)^2}+D_j$$
$$-\sqrt{x_1{}^2+x_2{}^2+x_3{}^2}-\tau_j c,$$
$$\tilde{D}_1=x_1-\tilde{D}\cos\alpha\sin\beta=x_1-\tilde{x}_1,$$
$$\tilde{D}_2=x_2-\tilde{D}\cos\alpha\cos\beta=x_2-\tilde{x}_2,$$
$$\tilde{D}_3=x_3-\tilde{D}\sin\alpha=x_3-\tilde{x}_3,$$

$\tilde{D}$ is the distance from the UAV to the active radar which is in origin of coordinates (Fig. 2), $\tilde{x}_1,\tilde{x}_2,\tilde{x}_3$ are UAV-coordinates measured by the active radar. Unmanned aerial vehicles and active radar position in the accepted coordinate system is shown in Fig. 3.

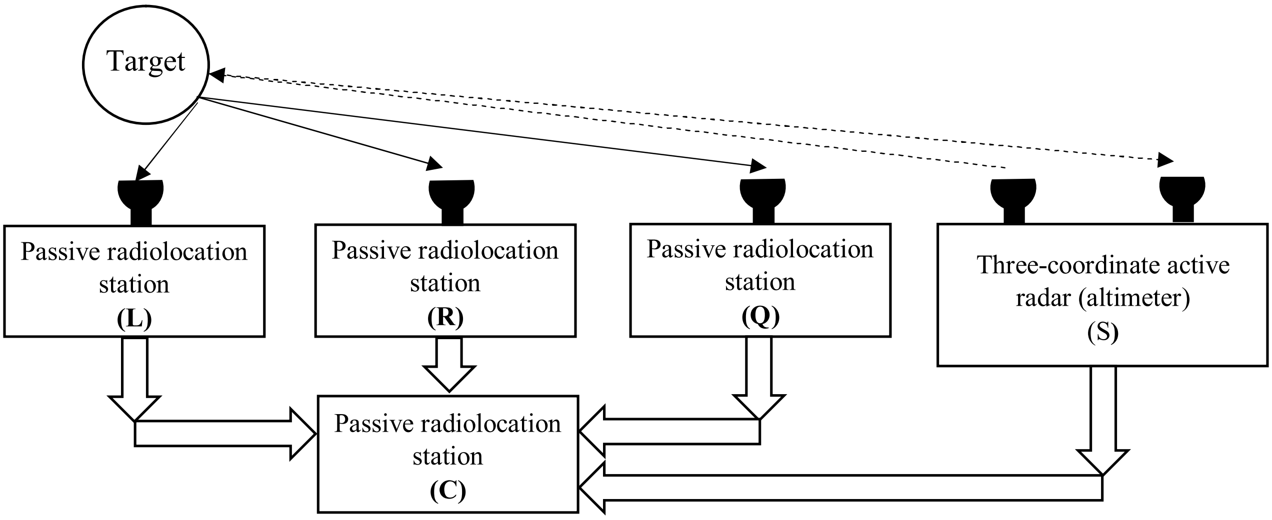

Fig. 1. System a complex of passive radiolocation – three-coordinate active radar (altimeter)

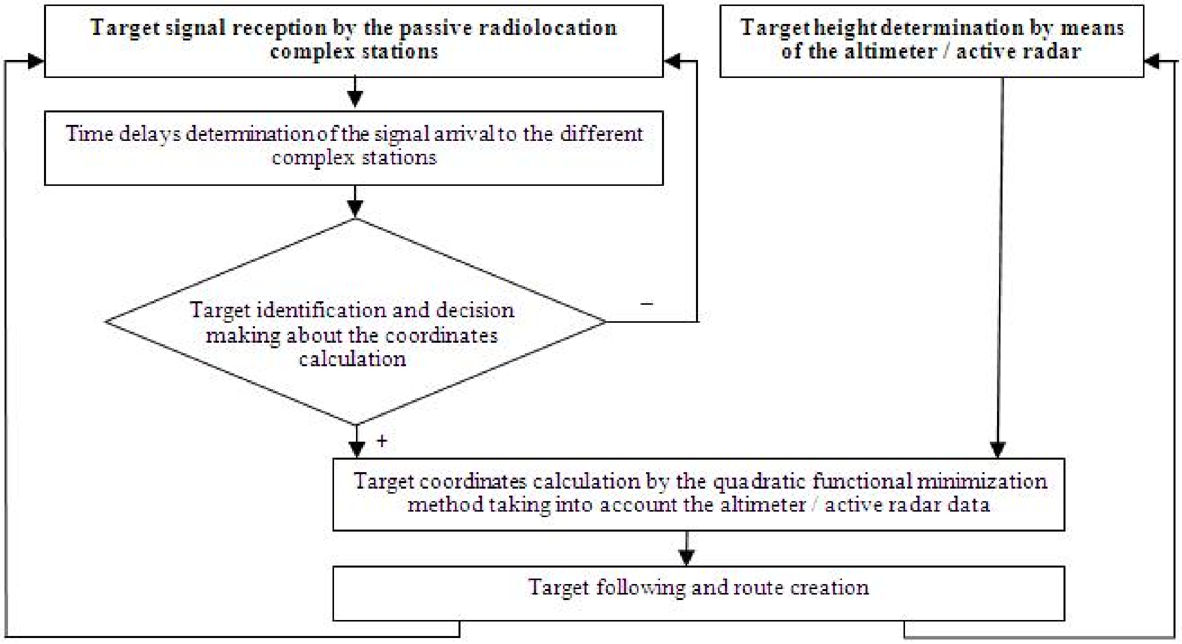

Fig. 2. Target coordinates determination flowchart by the passive-active radio monitoring system on the basis of the extremal TDOA-setting

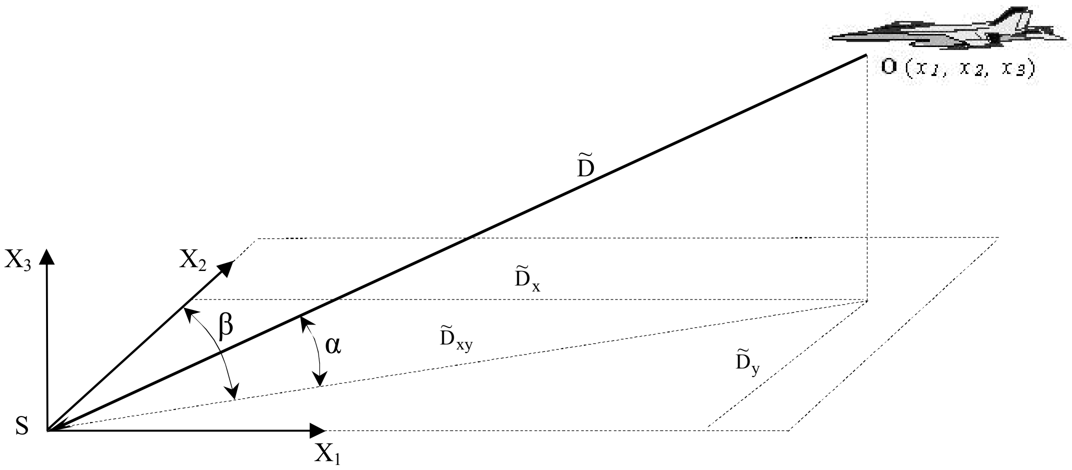

Fig. 3. Target and active radar positions in the accepted coordinate system

In case of the system operation “passive radiolocation complex – active radar” when $\sigma_{\tilde{x}_1}, \sigma_{\tilde{x}_2}, \sigma_{\tilde{x}_3} \le 0.2$, RMS-deviation of coordinates of x_1 and x_2 decrease practically by one order, RMS-deviation of coordinate x_3 decreases approximately by two orders, RMS-deviation of distance *D* from target to the coordinates origin also decreases practically by two orders.

In case $0.2 \le \sigma_{\tilde{x}_1}, \sigma_{\tilde{x}_2}, \sigma_{\tilde{x}_3} \le 0.3$, that is when RMS-deviation of the active radar error in limits or exceeds RMS-deviation of the signal arrival delay period at the each of the stations, RMS-deviation of coordinates x_1 and x_2 decreases by 4 times, RMS-deviation of coordinate x_3 decreases by two orders, and RMS-deviation of distance *D* from UAV to the coordinates origin also decreases approximately by 4 times.

V. CONCLUSIONS

Active and passive radiolocation systems integration allows to lower the measurement error of the UAV coordinates significantly (up to 50 %) and by that to raise efficiency of air defence systems in general.

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В. М. Синєглазов, Р. Л. Пантєєв, В. М. Ткаченко. Особливості сумісного використання активних та пасивних радіолокаційних систем

Проаналізовано методи виявлення та ідентифікації безпілотних літальних апаратів, а також підходи до визначення їх координат, які можуть бути використані в складних системах «комплекс пасивної радіолокації - висотомір» та «комплекс пасивної радіолокації – активна радіолокаційна станція». Наведено математичний апарат рішення задачі в умовах інформаційної надмірності шляхом мінімізації квадратичного функціоналу. За допомогою методу статистичних випробувань проаналізовано зменьшення похибки визначення координат безпілотного літального апарату.

Ключові слова: пасивний радіолокаційний комплекс; виявлення; ідентифікація; розрахунок координат; квадратичний функціонал; надлишкова інформація.

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В. М. Синеглазов, Р. Л. Пантеев, В. Н. Ткаченко. Особенности совместного использования активных и пассивных радиолокационных систем

Проанализированы методы обнаружения и идентификации беспилотных летательных аппаратов, а также подходы к определению их координат, которые могут быть использованы в сложных системах «комплекс пассивной радиолокации – высотомер» и «комплекс пассивной радиолокации – активная радиолокационная станция». Приведен математический аппарат решения задачи в условиях информационной избыточности на основе минимизации квадратичного. С помощью метода статистичеких испытанийтпроанализировано уменьшение ошибки определения координат беспилотного летательного аппарата.

Ключевые слова: пассивный радиолокационный комплекс; обнаружение; идентификация; определение координат; квадратичный функционал; избыточная информация.

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