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ABOUT ALGORITHMS OF TARGET POSITIONING

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Abstract—*Software has been developed for the system most suitable for wind shear detection. The formulation of the target designation problem is presented. The features of modern radars are considered. The aim of the work is to find the most suitable system for detecting wind shear and to develop software for this system that offers the pilot a turnkey solution for flying through the danger zone of wind shear. The paper presents the definitions of wind shear, statistics of air crashes caused by this phenomenon. The systems for determining wind shear are described and the most suitable system is selected. The principle of operation and the algorithm of operation of the Doppler radar station are given. A simulation of the detection of a dangerous wind shear zone was carried out. The pilot uses the proposed software solution. Thus, the task of determining the wind shear zone and the decisions proposed on this basis to fly around the dangerous zone have been completed. The results show that introducing random noise into labeled samples degrades the accuracy of the model, while introducing random noise into unlabeled data can, on the contrary, increase the accuracy of the model.*

Index Terms—Wind shear; doppler radar; algorithm; modeling; target designation; dangerous zone; software.

I. INTRODUCTION

Wind shear, sometimes called wind gradient, is the difference in wind speed and / or direction over a relatively short distance in the atmosphere. Atmospheric wind shear is usually described as vertical or horizontal wind shear.

Imagine a situation where the pilot receives information about the wind shift from the onboard equipment, then on the walkie-talkie from the dispatcher. Wind shear data may vary slightly, and there are many instructions on how to proceed. There is little time to make a decision, and the decision itself is important because it affects flight safety. The pilot is not able to absorb all the information in a short time and find one right solution for further action. But an automated system can help him make a decision, which will quickly process all the data on the wind shift and give the right decision on how to act.

The most important parameter of wind shear is its indicator, which is determined by the formula:

$$v_2 = v_1 \cdot \left(z_2 / z_1\right)^a, \tag{1}$$

where v_1 is the speed at the height z_1; v_2 speed at height z_2; a wind shear index [1].

II. PROBLEM STATEMENT

To begin with, the phenomenon of wind shear must be determined in order to further decide what to do in a particular situation.

There are systems for detecting wind shear, such as:

1) The Low Level Wind Shear Notification System (LLWAS) is a ground-based system for detecting wind shear near an aerodrome. The system uses anemometers for its work.

2) NEXRAD or Nexrad (Next Generation Radar) is a network of 160 high-resolution meteorological radars. These radars are located on the ground and are used to determine weather precipitation in the atmosphere, it allows you to predict the weather in different regions.

3) The on-board wind shear prediction system is located on board the aircraft and issues a warning of a wind shear ahead [5].

4) Terminal Doppler Meteorological Radar (TDWR) is a Doppler meteorological radar system with a three-dimensional "pencil beam", used mainly to detect dangerous conditions of wind, precipitation and wind shear at large airports and near them.

Terminal Doppler Meteorological Radar uses a carrier wave in the frequency band 5600-5650 MHz (wavelength 5 cm), with a narrow beam and an angular resolution of 0.5 degrees, and has a peak power of 250 kW. In terms of reflectivity, the distance resolution is 150 meters (500 feet) within 135 kilometers (84 miles) of radar and 300 meters (1000 feet) of 135 kilometers (84 miles) to 460 kilometers (290 miles) of radar. The reason for this difference is that the width resolution, being angular, at a greater distance, the beam width becomes quite large, and to obtain better averaging of the data in resolution, it is necessary to increase the number of pulses in the range. This cut-off is arbitrarily set for software at 135 kilometers (84 miles).

The main advantage of TDWR over previous meteorological radars is that they have a finer resolution, which means that it can see smaller areas of the atmosphere. The reason for the resolution is that TDWR has a narrower beam than traditional radar systems, and that it uses a set of algorithms to reduce ground noise [2].

Therefore, we use terminal Doppler meteorological radar to detect wind shift. The principle of radar is as follows: weather detection is based on the reflectivity of wind currents. The echo of the weather appears on the navigation display (ND) with a color scale that varies from red (high reflectivity) to green (low reflectivity). Echoes of meteorological radar vary in intensity depending on the size, composition and number of wind currents. Thanks to the use of orbital satellite systems and / or terrestrial communication channels, weather information can be sent to an airplane that is in flight, almost anywhere in the world [6].

Now let's build a block diagram of the system. It is shown in Fig. 1.

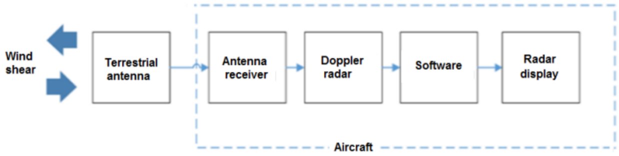

Fig. 1. Structural scheme of the system

The terrestrial antenna sends the beam reflected by wind flows, the antenna receives the reverse beam, and if it shelters, the shift shifts. A receiver antenna is established to receive the signal on the aircraft, which works on the same frequency with the terrestrial antenna. The accepted singal is submitted on doppler radar. It processes the signal according to a certain algorithm shown in the third section. The processed signal is sent to a program that visualizes all data on the radar display. It visualizes such parameters as aircraft coordinates and wind shift, taking into account the aircraft speed of the plane, offers a pilot flights.

III. PROBLEM SOLUTION

Signal Model of Target Echo

We assume that V_1 denotes the speed component of target scatter body; V_α represents the speed component of airplane along the radial. $\beta = 2\pi/\lambda$ is constant. We defined

$$\Delta\omega = \omega_i + \omega_\alpha = \beta(V_i - V_\alpha) = \frac{2\pi(V_i - V_\alpha)}{\lambda}. \quad (2)$$

The in-phase component I and quadrature Q component of the target echo signal can be expressed, respectively, as

$$I(nT_s) = \sum_{i=1}^{N} A_i \cos\left[\phi_i + \beta(V_i - V_\alpha) nT_s + \Delta\bar{\phi}\right] + \bar{n}(nT_s). \quad (3)$$

$$Q(nT_s) = \sum_{i=1}^{N} A_i \sin\left[\phi_i + \beta(V_i - V_\alpha) nT_s + \Delta\bar{\phi}\right] + \bar{n}(nT_s), \quad (4)$$

where $\bar{\phi}_i$ is the random phase of the scatter target and $\Delta\bar{\phi}$ represents the transmitted phase error. $\bar{n}(nT_s)$ is the receiver noise. n expresses the number of pulses. T_s is the pulse time interval.

Signal amplitude A_i can be obtained by radar equation and reflectivity factor. A_i can be expressed as

$$A_i = \sqrt{Rae \cdot E_t \cdot \xi \cdot Vol} \cdot G, \quad (5)$$

where

$$Rae = \frac{P_t \cdot \lambda^2}{(4 \cdot \pi)^3 \cdot R^4 \cdot R\_loss}, \quad (6)$$

where Rae is the constant of radar equation and R_loss represents the receiver loss. Vol indicates the volume of the scatter body. ξ shows the multipath fading factor. G is the antenna gain. E_t is wind shear wind field reflectivity.

Signal phase is mainly decided by the Doppler frequency shift. Doppler frequency shift consists of two parts, ω_i and ω_α.

The total rain echo signal phase can be expressed as

$$\psi = \bar{\phi}_i + \beta(V_i - V_\alpha) + \Delta\bar{\phi}. \quad (7)$$

The principle diagram of wind shear target echo simulation is shown in Fig. 2.

In order to simulate the whole space wind field within the scope of the $x - y - z$ three direction of the wind speed, we build a microburst wind shear of wind field model, and the simulation process is as follows:

1) The speed of the vertical flow

(a) The calculation of the radial distance

$$RC = \sqrt{(X\_XC)^2 + (Y - YC)^2}, \quad (8)$$

where X and Y are the airplane's x and y position coordinates and XC and YC are the center of wind field in x and y position. RC is the radial distance of airplane. The minimum value of RC is set to 2.0.

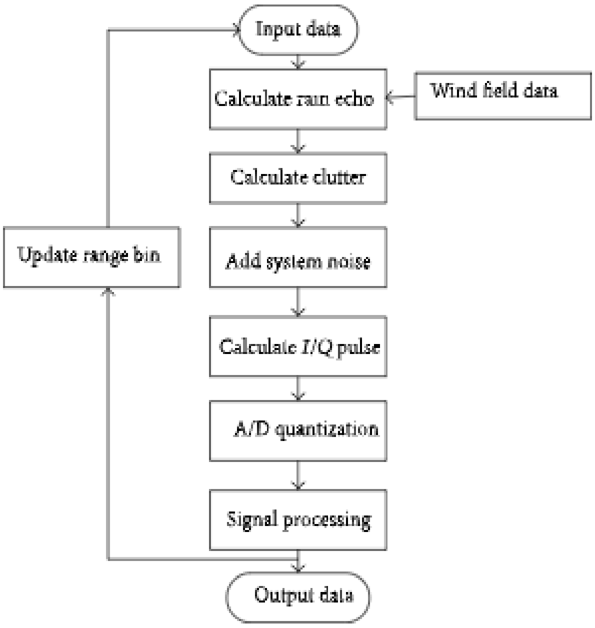

Fig. 2. The principle diagram of wind shear target echo simulation

(b) We define a parameter RA; RA is related to the position of airplane, wind shear, and distortion factor

$$RA = RT + \sqrt{RT^2 + R^2 \cdot \left(1 - GR^2\right)}, \qquad (9)$$

where

$$RT = R\cos A \cdot GR,$$

$$\cos A = \frac{X - XC}{RC} \cdot \frac{GX}{GR} + \frac{Y - YC}{RC} \cdot \frac{GY}{GR}, \qquad (10)$$

$$GR = \sqrt{GX^2 + GY^2},$$

where GX and GY are the distortion factors in x and y position. The minimum value of GR is set to 0.002. The minimum value of RA is set to 2.0.

2) The radial velocity of horizontal flow.

The variable of radial velocity distribution is defined by VRR: $VRR = 0; \quad H \geq HT$,

$$VRR = 0.75 \cdot GVZ \cdot VZO \cdot \frac{RA}{HT^2} \cdot \left(HT - H\right), \qquad (11)$$

where H is the height of airplane, VZO is the initial reference velocity, HT is the height limit of horizontal airflow, and GVZ is the gain factor of wind field.

The wind shear model

According to the changing rule of the horizontal wind ω_x and vertical wind ω_y, the following wind shear model is established:

$$\begin{aligned} \omega_x &= A\sin\left(\omega_0 t + \varphi_0\right), \\ \omega_y &= B\left[1 - \cos\left(\omega_0 t + \varphi_0\right)\right]. \end{aligned} \qquad (12)$$

In the formula, A and B denote the size of horizontal wind and vertical wind, respectively. $\omega_0 = \frac{2\pi}{t_0}$. t_0 shows the total time of the plane through the microburst. φ_0 expresses the initial phase. To solve the derivative t_0, we also can get

$$\begin{aligned} \omega_x &= A\omega_0 \cos\left(\omega_0 t + \varphi_0\right), \\ \omega_y &= B\omega_0 \sin\left(\omega_0 t\right). \end{aligned} \qquad (13)$$

The conclusions of the calculation are presented in Table I, according to these data simulated determination of wind shear. The simulations are shown in Figs 3 and 4.

TABLE I. DATA FOR SIMULATION

Variable	Value	Unit
Pulse repetition frequency	3500	Hz
Pulse width	1.5	us
Sampling interval	1	us
Operating frequency	9.0	GHz
Range resolution	150	m
Antenna gain	34	dB
Antenna beamwidth	2.8	dB
System noise	2.5	dB
Transmitter power	200	W

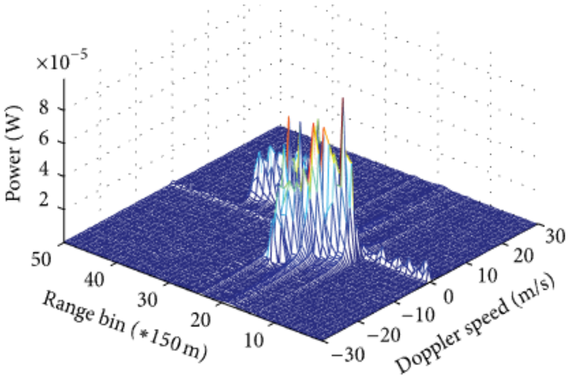

Fig. 3. Distribution of wind shift spectrum

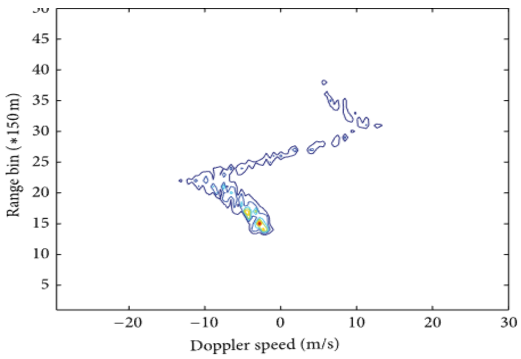

Fig. 4. Dangerous wind displacement zone

After we can use radar to determine the wind shear zone, develop radar software that offers a solution on the radar display in the form of a route around the danger zone, the pilot in turn decides whether to use the route proposed by the program.

The program is developed in the PYTHON programming language. It is recorded on an on-board computer specifically for on-board Doppler radar. The program uses the computing power of the computer and the radar display to display the result.

When the wind shift is detected by the terrestrial antenna, information about it is fed to the onboard radar, which in turn processes the signal. The processed signal is fed to the computer where the program works with it [8].

The software works according to the algorithm presented in Fig. 5.

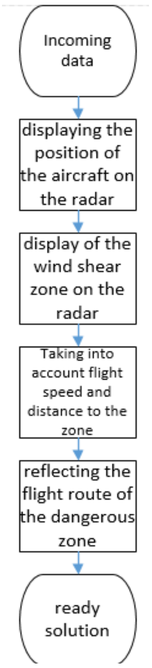

Fig. 5. Algorithm of software operation

IV. CONCLUSIONS

The paper considers the phenomenon of wind shear. The task of determining the zone of wind shear and calculating its index is set. An analysis of wind shear detection systems was carried out. This made it possible to choose the most appropriate system for this in the form of a Doppler radar. An algorithm of radar operation was developed, which made it possible to perform rough calculations according to this algorithm. Based on the calculated parameters listed in the table, the determination of the dangerous zone of wind shear was simulated. Modeling according to the parameters showed that the Doppler radar copes with the task of determination. This gave rise to the development of software that works together with the radar and displays the finished solution. The pilot uses the proposed software solution. In this way, the task of determining the zone of wind shear and, on the basis of this, proposing a decision to fly around the dangerous zone, has been completed.

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О. С. Глей, В. М. Синєглазов. Про алгоритми цілепозиціонування

Розроблено програмне забезпечення для системи, що найбільш підходить для виявлення зсуву вітру. Представлено постановку задачі цілепозиціонування. Розглянуто особливості сучасних радарів. Мета роботи – знайти систему, що найбільше підходить для виявлення зсуву вітру, і розробити для цієї системи програмне забезпечення, що пропонує пілоту готове рішення для прольоту небезпечної зони зсуву вітру. Діяльність представлені визначення зсуву вітру, статистика авіакатастроф, викликаних цим явищем. Розписано системи визначення зсуву вітру та обрано найбільш підходящу систему. Наведено принцип роботи та алгоритм роботи доплерівської радіолокаційної станції. Проведено моделювання виявлення небезпечної зони зсуву вітру. Пілот використовує запропоноване програмне рішення. Таким чином, завдання щодо визначення зони зсуву вітру та запропоновані на цій основі рішення про обліт небезпечної зони виконані. Результати показують, що введення випадкового шуму в марковані зразки погіршує точність моделі, а введення випадкового шуму в немарковані дані може навпаки підвищити точність моделі.

Ключові слова: зсув вітру; доплерівський радар; алгоритм; моделювання; цілепозиціонування; небезпечна зона; програмне забезпечення.

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О. С. Глей, В. М. Синеглазов. Об алгоритмах позиционирования цели

Разработано программное обеспечение для системы наиболее подходящей для обнаружения сдвига ветра. Представлена постановка задачи целеуказания. Рассмотрены особенности современных радаров. Цель работы – найти систему, наиболее подходящую для обнаружения сдвига ветра, и разработать для этой системы программное обеспечение, предлагающее пилоту готовое решение для пролета опасной зоны сдвига ветра. В работе представлены определения сдвига ветра, статистика авиакатастроф, вызванных этим явлением. Расписаны системы определения сдвига ветра и выбрана наиболее подходящая система. Приведены принцип работы и алгоритм работы доплеровской радиолокационной станции. Проведено моделирование обнаружения опасной зоны сдвига ветра. Пилот использует предложенное программное решение. Таким образом, задача по определению зоны сдвига ветра и предложенные на этой основе решения об облете опасной зоны выполнены. Результаты показывают, что ввод случайного шума в маркированные образцы ухудшает точность модели, а ввод случайного шума в немаркированные данные может наоборот повысить точность модели.

Ключевые слова: сдвиг ветра; доплеровский радар; алгоритм; моделирование; целеуказание; опасная зона; программное обеспечение.

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