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THE POSSIBILITY TO USE POLARIMETRIC RADAR FOR ATMOSPHERIC TURBULENCE INTENSITY ESTIMATE

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Approach, that is presented in this paper proposes to estimate the turbulence intensity by spectral components of polarization signals as random process. It allows to decrease time for signal processing. We consider turbulence as stochastic process. Liquid hydrometeors that are the cause of polarization spectrum appearance are considered as the filter from which the output signal is taken for further transmitting and processing. The requirements to the line for polarization spectrum transmission are represented. The calculations show that the transmission line should be capable to transmit frequencies from about zero to those that are determined by the sampling frequency that is enough to define polarization spectrum parameters as a random process with given accuracy.

Викладено підхід, що дозволяє оцінити інтенсивність турбулентності за спектральними оцінками поляризаційного сигналу як випадкового процесу та зменшити час обробки сигналу. Турбулентність розглянуто як випадковий процес, рідкі гідрометеори, що викликають появу спектра поляризації – як фільтр, з якого знімається сигнал для подальшої обробки та передачі. Обґрунтовано вимоги до тракту передачі спектра поляризаційного сигналу. Показано, що тракт має бути спроможним передавати діапазон частот від значень, що є близькими до нуля, до частот, що визначаються частотою дискретизації, що є достатньою для визначення з заданою точністю параметрів поляризаційного спектра як випадкового процесу.

Introduction

Severe atmospheric turbulence is denoted as dangerous for aviation phenomenon [1].

Turbulence is presence in the atmosphere of eddies of different sizes and directions. The severe turbulence can leads to aircraft damages and even be cause of aircraft control loss. Therefore, ICAO documents indicate the necessity in providing aircraft crew with reliable and opportune information about presence of en-rout atmospheric turbulence. The methods of turbulence intensity estimate that are used nowadays allow to retrieve information about severe turbulence by indirect measurements, or by phenomena that usually are accompanied with turbulence. This approach makes the on-line turbulence detection and its intensity estimate quite complex.

Analysis of studies and publications

In [2; 3; 4] the methods of turbulence detection and its intensity estimate with indirect measurements are presented. Such methods use parameters and characteristics that are compared with an eddy dissipation rate ε. Eddy dissipation rate ε is a fundamental parameter of turbulence that characterizes the turbulence intensity [2; 4].

ICAO recommends to use the eddy dissipation rate for turbulence intensity estimate. ε is obtained with indirect measurements as well.

An example of turbulence severity classification from the viewpoint of influence onto aircraft done on the basis of ε is shown in table [5].

The value of ε in cumulonimbus clouds *Cb* , that are the most dangerous for aircraft navigation and flight operation, can reach 1000 cm^2/s^3. It is necessary to make additional calculations for mentioned methods realization.

This fact decreases the estimate efficiency. In case of many phenomena connected with wind including turbulence, the on-line detection is one of the basic requirement due to the short existence, sudden appearance and disappearance of phenomena [1].

Problem statement

Taking into account all mentioned above, it is would be useful try to find such parameters and/or characteristics for turbulence estimate that can be considered as direct indicators of the phenomenon and increase measurements efficiency and probability.

Analysis of [6; 7; 8] shows that it is possible to use polarimetric parameters of radar signal to solve the put problem.

Classification of turbulence intensity compare to eddy dissipation rate

ε, $cm^2 \cdot s^{-3}$	Intensity scale
< 0,2	Negligible
0,2–3,4	Light
3,4–42,9	Moderate
42,9–550	Heavy
> 550	Severe

It is shown in [9] that in case of the turbulence, the liquid hydrometeors are deformed and change their spatial orientation under the acting acceleration of air currents.

It leads to appearance of crosspolar component of received radar signal or/and changing intensity of copolar signals.

Polarimetric methods

In nature the most hydrometeors have nonspherical shape. Polarization of scattered signal depends on the shape and orientation of drops. Therefore, it is possible to get information about hydrometeor shape by measuring polarization characteristics of radar antennas.

Radars with polarization diversity can change polarization of transmitted signal and provide obtaining two orthogonally polarized waves.

The use of such radars allows to determine the hydrometeor size, shape, spatial orientation and thermodynamical state [2; 4]. The most common are the next technique for measuring polarization parameters [2]:

1) $\vec{e}_r = \vec{e}_i = \vec{e}_v$;

2) $\vec{e}_r = \vec{e}_i = \vec{e}_h$;

3) $\vec{e}_r = \vec{e}_v \cap \vec{e}_r = \vec{e}_h$.

In the first case transmitter transmits vertically polarized wave and receiver receives vertically polarized wave. In the second case transmitter transmits horizontally polarized wave and receiver receives horizontally polarized wave.

These two techniques are so-called copolar measurements.

In the third case transmitter transmits horizontally polarized wave and receiver receives vertically polarized wave and it is denoted as crosspolar measurement

Connection of polarimetric parameters with characteristics of liquid hydrometeors under the wind influence

In case of turbulence, eddies of different sizes are created in the atmosphere.

It allows to consider the turbulence as stochastic process. In [8] it is shown that changing wind vector leads to changing hydrometeors velocities, their shape and spatial orientation.

This changing is a response on the wind gradient influence.

Therefore, connection between changing wind speed and polarization spectrum of received signal are defined with the drop shape and its orientation. The time history is possible to take into account with help of drop transient response.

The drop in this case is considered as some filter, that convert stochastic process of changing wind gradient into process of changing polarization spectrum of signal.

In papers [6; 10] the drop transient response for the cases of drop speed acceleration and deceleration was represented with formulas that include so-called drop constant τ_k [11].

The drop constant τ_k characterizes transient process of drop movement and takes into account drop mass, drop equivalent diameter, drop liquid density and air viscosity .

Accordingly to formulas of drop transient response [10] the drops of different sizes respond to wind gradient with different speed. This happens because the sounding volume contains drops with different orientation.

When wind gradient presence, the received cross- and co-polarized signals are the signal spectrum with different polarization angles. The width and life time of the spectrum is defined with hydrometeor size distribution and turbulence intensity.

Thus, the problem of turbulence evaluation can result into observing cross- or co-polar signals as stochastic process as well as evaluation of their parameters. Under such approach it is necessary to agree upon the a priori statistical model of turbulence as stochastic model.

As it was mentioned, turbulence, as well as other dangerous for aviation weather phenomena connected with wind, appears, disappears and changes direction randomly. It gives possibility to consider turbulence, in whole, as a local nonstationary process.

Over the some time interval process can be considered as stationary, especially in stable weather phenomena on height altitudes.

Also it is necessary to take into account that operative statistical evaluation of turbulence is made for relatively short time, approximately for tenth seconds or minutes, while parameter evaluation might be made for one realization of stochastic process. In the limits of such time interval it is admissible to consider the process as stationary and use simpler algorithms and devices for its parameter evaluation [9; 12].

The other important condition is to choice of observation “window” that is the time interval of random process of observation and sampling frequency as well as frequency characteristic of the channel in which polarization signal is processed and transmitted.

The frequency characteristic should be enough to transmit polarization spectrum.

The last condition is important because in this paper the drop is considered as a filter and output signal taken from the filter should be transmitted and processed.

In [10] the calculation of scanning parameters for determination of statistical characteristics of received polarization signal was made.

The calculation was made taking into account dynamic properties of liquid hydrometeors as signal reflectors.

In paper [10] also the sampling parameters of signal was grounded. These parameters are used for estimation of signal as a random process.

Requirements for Amplitude Frequency Characteristic of the channel for polarization signal transmition

Therefore, it is interesting to prove requirements for Amplitude Frequency Characteristic of the channel for polarization signal transmition.

Let us to use Nayquist and Kotelnikov theorem to determine upper boundary frequency of Amplitude Frequency Characteristic. According to the theorem the upper boundary frequency of Amplitude Frequency Characteristic of the channel is connected with sampling interval by the ratio:

$$F_u = \frac{1}{2\tau_u},$$

where τ_u is time constant of the drop whith the smallest diameter.

The lower boundary frequency of Amplitude Frequency Characteristic is determined by the necessary observation interval.

$$F_l = \frac{1}{2\tau_l}, \qquad (1)$$

where τ_l is observation interval.

Using the data of paper [10] we have:

$F_u \approx 4{,}55$ Hz and $F_l \approx 0{,}047$ Hz.

The lower frequency of the spectrum can be even smaller than frequency calculated with formula (1) in case of increasing observation interval. It can be useful when it is necessary to increase accuracy of random process parameters estimate.

Thus, it is reasonable to use direct current amplifier with minimally enough upper boundary frequency in the channel of signal transmitting.

Conclusions

1. In the approach, that is presented in this paper the turbulence intensity is proposed to estimate by spectral components of polarized signals as random process. It allows to decrease time for signal processing.

2. It is reasonable to use direct current amplifier with relatively small upper boundary frequency for transmitting polarization signal. Significant increasing upper boundary frequency is not wanted dew to increasing the noise level of signal.

3. The technical realization of the channel for amplifying signal with polarization spectrum, considered in this paper, is not very difficult for modern engineering achievements.

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