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NUMERIC ANALYSIS OF SODAR ECHO SIGNALS

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The results of analysis based on the FFT with some methods of evaluating the power spectrum of sodar echo signals for investigating the vertical profiles of wind speed in lower atmosphere are discussed in the article. The best from the point of view of spreading of spectrum and computing time occurs to be the Goodman–Enochson–Otnes method (GEO) with frequency weight window. The results of applying the GEO method to evaluating the vertical profile of wind speed in lower atmosphere by means of MUT sodar are presented.

1. Introduction

The investigation of the lower layer of the atmosphere and the processes occurring there is the subject of interest for many scientists in various scientific fields and learning the structure of the lower layer and its main characteristic is the basic interest of the physics of the atmosphere. Applying conventional measurements equipment to investigation of the wind, temperature, humidity and turbulence in the lower layer of the atmosphere, along with advanced numeric methods of modelling led to great progress in analysis of physical phenomena in this part of the atmosphere. Simultaneously, in all those situations where direct measurement is problematic from technical point of view or impossible as far the measurement range is concerned, the detection methods become relevant.

From the teledetection methods the active acoustic sounding of the atmosphere by means of sodars seems to be particularly attractive, exceptionally for investigation of the wind vertical structure of the lower atmosphere [1, 2]. The necessity of processing the sodar echo signals in real time, relevant especially in detection of hazardous for aviation rapid changes of the wind speed and direction, made the constructors of the contemporary sodars choose the Fast Fourier Transformation (FFT) as the method for the analysis of the Doppler spectra [3].

The results of analysis based on the FFT method are shown below along with selected methods of determination of the momentary wind speed vertical structure in the lower atmosphere.

2. The methods of determination of the power spectra of echo signals

The main reason for determination of the power spectrum of a physical process is investigation of its frequency structure, which contains important information relevant to the basic features of the investigated physical structures. In the case of the wind structure of the lower atmosphere investigation by means of the sodar made by MUT (Military University of Technology) the power spectrum of echo signals was used to evaluate the Doppler shift of frequency of the echo signals in comparison with the emitted signals. However direct computing the power spectra of echo signals by means of Fast Fourier Transform may results in leak out the spectrum [4] or its negative values [5]. To determine the power spectrum of sodar echo signals the following was applied:

1. the Blackman – Tuckey's correlation function method using FFT and Hamming's window [6] — called the BT method,
2. Goodman – Enochson – Otnes method [7] — called GEO method.

The Hamming's window is a time window and Goodman – Enochson – Otnes' window is a frequency window. The analysis of sodar echo being the response of the investigated medium atmosphere boundary layer to probing by an acoustic wave, of 1.000 Hz frequency, was done. The received analog signal was scanned with the frequency of 5.120 Hz by means of 12-bit A – D converter. The receiving time was equal to about 5 seconds, which corresponded to 25.000 samples and sounding the layer 800 m thick. The power spectrum of sodar echo signal segments containing 1.024 and 2.048 samples was evaluated with the BT and GEO methods applied.

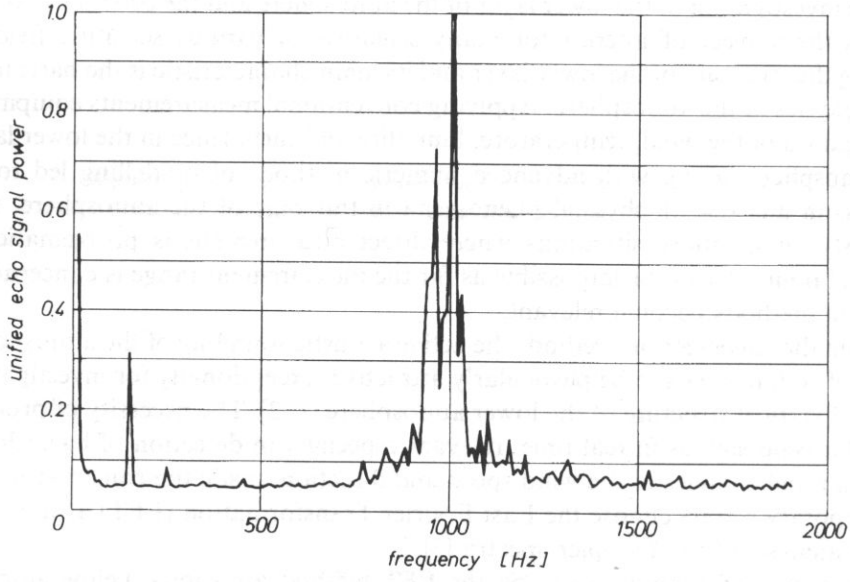

Fig. 1. The power spectrum of sodar echo signals evaluated by the Blackman – Tuckey method with Hamming window.

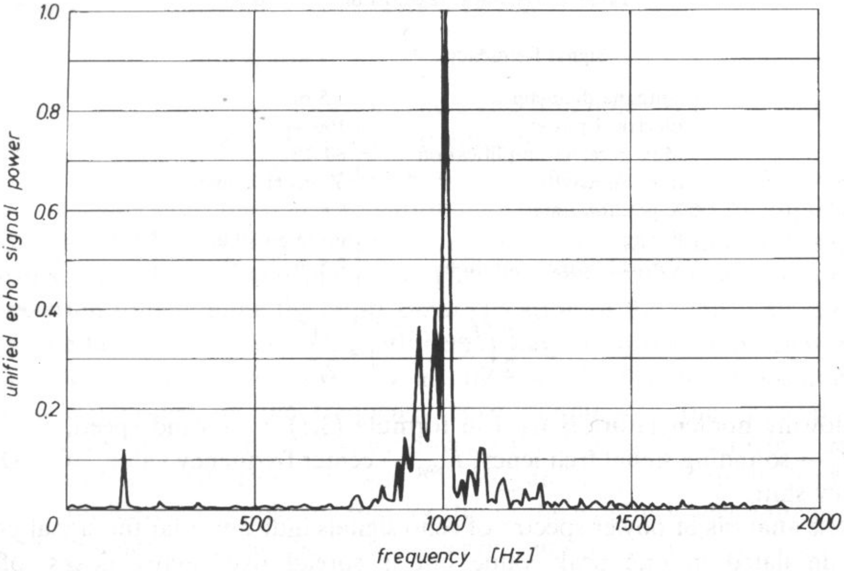

Fig. 2. The power spectrum of sodar echo signals evaluated by the direct method with Goodman – Enochson – Otnes window.

Figures 1 and 2 shows the power spectrum of sodar echo signal of one of the segments received with the BT and GEO methods applied, respectively. The comparison of Fig. 1 and Fig. 2 show that the power spectra in BT method are more spread than in the GEO one (in GEO method the echo signal power lies in narrower frequency range). These effects influence on the precision of wind speed evaluation. The BT method suffers higher level digital noises. Taking also into consideration the computing time when BT was used, the BT method was abandoned.

3. An application example of the Goodman – Enochson – Otnes method with balance method for evaluation of wind vertical profile in the lower atmosphere by means of sodar made by MUT

The Goodman – Enochson – Otnes' method was used for evaluation of wind vertical profile in the lower atmosphere during field investigation at the training area of Meterology Institute of MUT in May 1993. A monostatic Doppler sodar MUT was used [2]. The technical description of the sodar is given in Table 1. The atmosphere was sounded by the 1.000 Hz signal. The received echo signals, amplified and converted, were analysed according to the GEO method. The evaluated power spectra of the echo signal segments allow to estimate the Doppler shift Δf against the frequency of the sounding signals. The wind speed at an atmosphere level is evaluated from:

Table 1. Technical features of MUT sodar

Signal frequency	1 kHz (2 kHz)
Antenna diameter	1.5 m
Electrical power	100 W
Max. receiver amplification	80 dB
Impulse length	50 ms (100 ms)
Repetition time	8 s
Range	up to 1.000 m
Vertical range resolution	8.5 m (17 m)

$$v=\frac{c}{2}\left(\frac{f_{\mathrm{mean}}-f_0}{f_0}\right)=\frac{c\Delta f}{2f_0} \tag{3.1}$$

The following nomenclature is used in formula (3.1): v — wind speed, c — sound speed, f_0 — sounding signal frequency, f_{mean} — center frequency value, Δf — Doppler frequency shift.

Precise analysis of power spectra of echo signals indicates that the signal power is not accumulated in one peak value but is spread over many peaks, often of comparable power. Figure 3 shows example fragment of power spectrum of echo signal as an illustration to the above mentioned phenomenon. The spreading of power spectra of received signals is mainly due to disturbing noises of various origins. The disturbing noises presence causes that the center frequency value f_{mean} of sodar echo signals, defined as the first moment of the signals power spectrum [6, 7], actually gives the center of gravity of the spectrum of signal and noise:

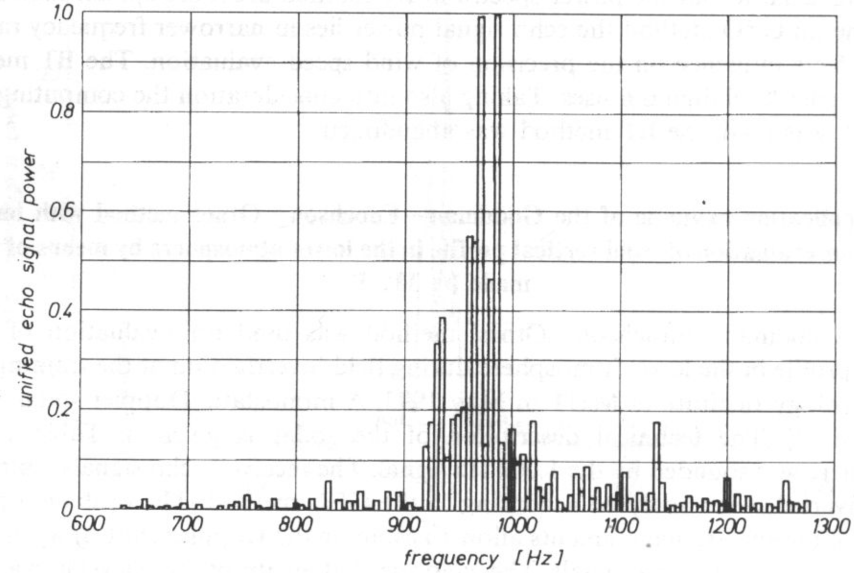

Fig. 3. Sector of the power spectrum of the echo signal of MUT sodar.

$$f_{s+n}=\frac{\int (G_s+G_n)f df}{\int (G_s+G_n)\, df} \tag{3.2}$$

where f_{s+n} — center frequency value of echo signal and noise, G_s — signal power, G_n — noise power, f — the sounding signal frequency.

For precise evaluating of the wind speed it is necessary to precisely evaluate the Doppler frequency shift. Such an evaluation may be accomplished by application of the balance method [7]. The procedure is carried out in two stages with successive improvements in accuracy and precision. The first stage consist of search over the entire spectrum to determine the approximate location of the echo. This is done by balancing method whereby the entire spectrum is scanned by fixed moving window of width Δf_B, devided into two subwindow of $\Delta f_B/2$ width. The initial position of the window is established by the frequency corresponding to the spectral line of maximum power in the segment. The window is shifted along the frequency axis. The power contained in each of the two windows, $G_{l,i}$ and $G_{p,i}$ respectively, is measured the echo is considered acquired for that locatio of the windows where the difference reaches the minimum. Then the ratio between such levels and the average level obtained in any other location is calculated.

$$|\Delta G_i| = |G_{l,i}-G_{r,i}| \tag{3.3}$$

Here the following abbreviations are used: ΔG_i — difference between the right and left sub windows, G_l — power in the left sub window, G_r — power in the right sub window.

The second stage of the procedure is determination of the "center" frequency f_{mean}, and, consequently, of the radial wind is obtained. The central frequency value is defined by the first moment of spectrum (according to GEO method):

$$f_{\text{mean}}=\frac{\sum_{0}^{\Delta f_B} G_i f_i}{\sum_{0}^{\Delta f_B} G_i}, \tag{3.4}$$

where f_{mean} — center frequency value of the power spectrum of the echo signal, Δf_B — window width, G_i — spectral line power of the spectrum at f_1 frequency, f_i — frequency of i-spectral line in window ΔF_B.

Figure 4 shows the example of the difference spectra of the power evaluated in left and right subwindow when the power spectrum of echo signal is scanned according to the balance method. The minimum of the difference as shown in Fig. 4 defines precisely the center frequency value f_{mean} of the echo signal. The GEO method with balance method was applied to estimation of the wind speed vertical profile in lower atmosphere by means of MUT sodar. Figure 5 shows examples of vertical profiles of horizontal components of wind speed evaluated for equal window width 80 Hz in balance method in various lengths of the analysed sequence.

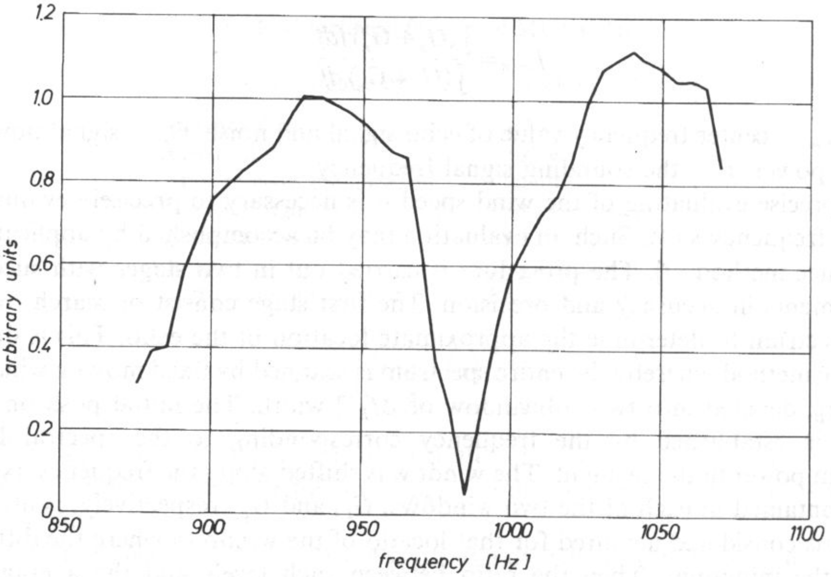

Fig. 4. The power difference between left and right windows for power spectrum of signal analysed by the bvalance method.

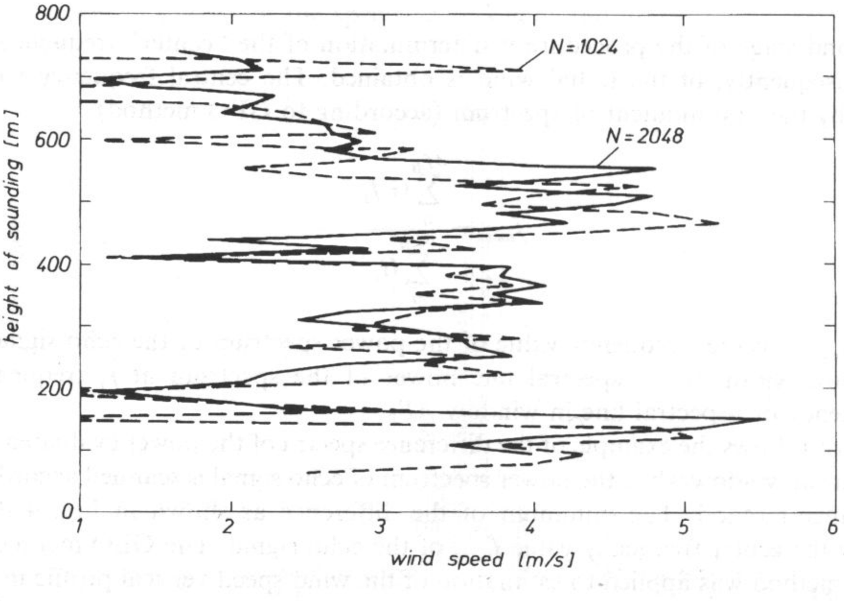

Fig. 5. Vertical changes of the momentary horizontal component of the wind speed evaluated by the balance method with 80 Hz window for both profiles; solid lines $N=1.024$ samples, dashed lines $N=2.048$ samples.

The window width was required to take into consideration all relevant peak values of the power spectrum in the sequence.

Figure 5 shows the differences of two vertical profiles of horizontal component of wind speed caused by different length of analysed measurement segments. For a segment 1.024 samples long the Doppler frequency shift origins from the atmosphere layer 64 m thick; for the 2.048 samples long segment the thickness is 128 m. It may result in relevant differences of evaluated wind speeds at a level because of mutual compensation of negative and positive Doppler frequency shifts caused by air movement in various directions in the same layer. The greater length of the segment involves greater averaging range and, consequently, reduction of short period wind pulsations.

The vertical profiles of wind speed changes shown on Fig. 5 are characteristic for wind speed profiles in lower atmosphere with developed convection.

4. Conclusion

Based on the analysis the following may be concluded:

1. The tests performed enabled the initial estimation of the application range and effectiveness of the proposed method of numeric sodar echo signal conversion for evaluation of wind speed vertical profile in lower atmosphere.

2. The evaluated Goodman – Enochson – Otnes method combined with the balance method proved to be effective for real time evaluation of wind speed at a certain level.

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