ULTRASONIC SYSTEM FOR STUDYING SPATIOTEMPORAL CHARACTERISTICS OF WIND AND TEMPERATURE FIELDS

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The ultrasonic system is developed for studying spatiotemporal characteristics of wind and temperature fields.

Ultrasonic anemometers–thermometers are often used for studying turbulent characteristics of the surface atmospheric layer and interaction between the atmosphere and the ocean.[1–5] Absence of moving parts, relatively small time constant, selective sensitivity to a desired wind velocity component, and the possibility to measure temperature fluctuations[4] make this device very attractive when studying atmospheric characteristics.

An automated ultrasonic system for studying spatiotemporal characteristics of temperature and wind fields was developed at the Institute of Atmospheric Optics SB RAS based on the experience accumulated in this area. The exterior view of the system is shown in Fig. 1. The system allows one to measure mean and fluctuation (turbulent) characteristics of wind velocity components and temperature. The phase method of measuring the wind velocity and temperature with multiparameter feedback[6] is implemented in the system.

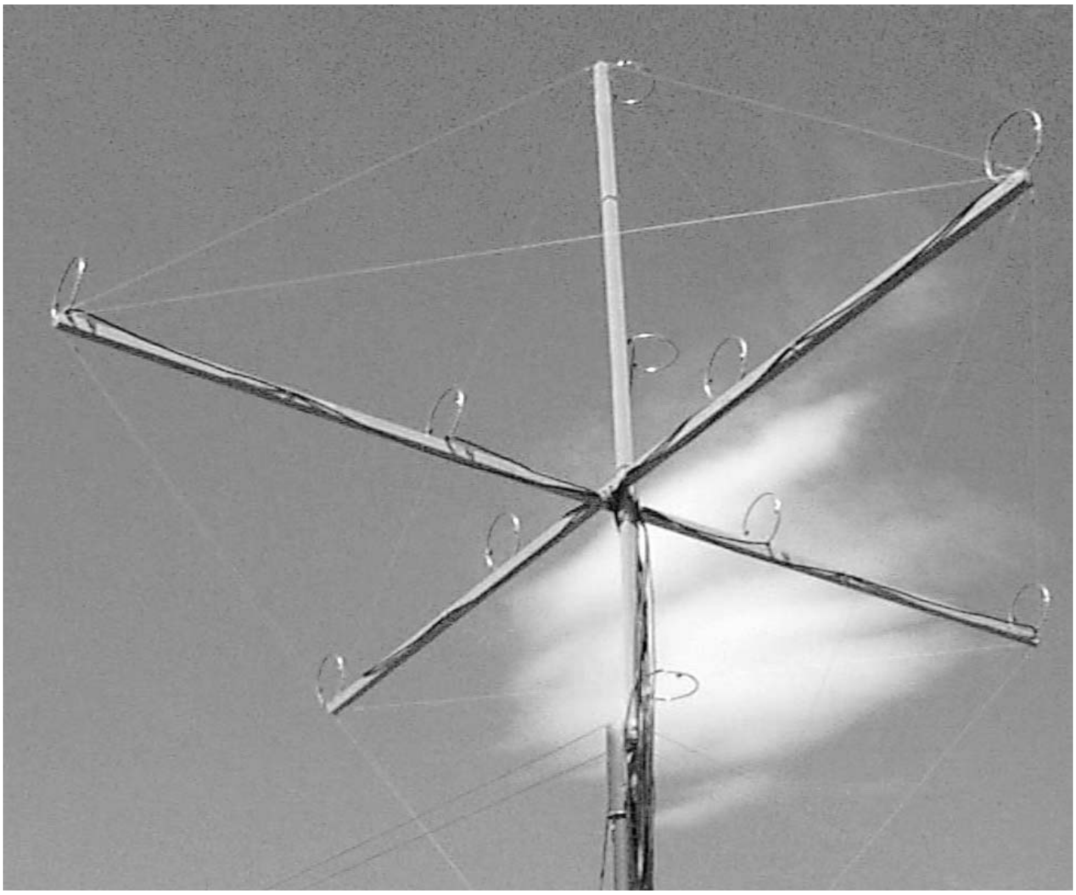

FIG. 1. External view of the ultrasonic system.

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Measurement range for wind velocity, m/s	0 – 20
Value of the least significant digit of the wind velocity, m/s	0.02
Temperature measurement range, °C	–10 – +50
Value of the least significant digit of the temperature, °C	0.019
Inner measurement rate, Hz	38
Maximal output rate, Hz	4
The number of measured parameters	24 (12 for wind and 12 for temperature)
Maximal length of a power supply line, m	300
Power supply, W	no more than 3

The system is designed as a rigid structure shaped as a tetrahedron with twelve unidimensional ultrasonic sensors arranged orthogonally in a space. The parameter L/D (L is the base length, D is the transceiver diameter) determines the level of their shading. It is eCual to 12, what corresponds to mean value for the devices of such class.[2,4] Each sensor is designed as an open ring with a thread joint reCuired for measuring the base length at their temperature calibration. MA40S3S ultrasonic sensors manufactured at Murta (Japan) are used as the transceivers. They operate at the basic resonance freCuency of 40 kHz. Twelve 1-mm capron threads fix the ends of axial bearing battens in space and provide the construction rigidity.

To perform investigations under field conditions, the measuring unit of the setup is fixed to a 4-m high meteorological mast. The measuring unit is capable to change its orientation in three planes. It allows a successive recording of spatiotemporal series of data on longitudinal, transverse, and vertical wind velocity components. The system can be easily transformed from the tetrahedron to a line of 12 sensors as shown in Fig. 2. This allows spatiotemporal characteristics to be measured at 12 points along the 12-m long base.

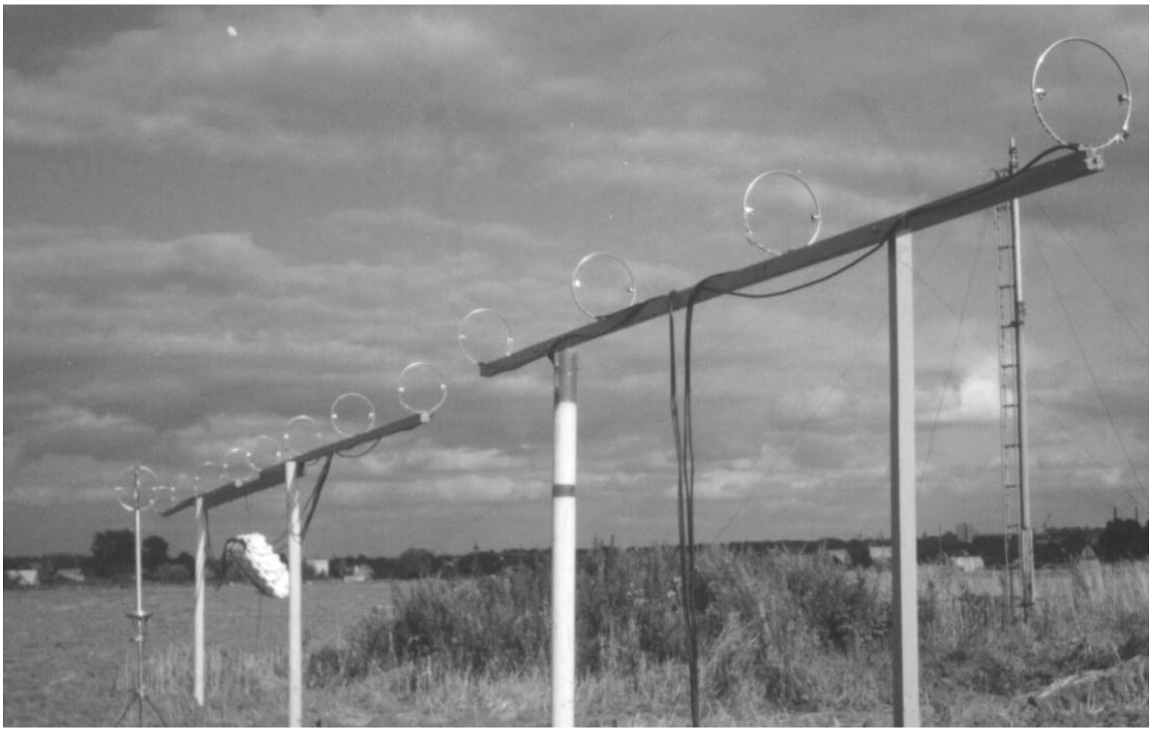

FIG. 2. An example of transformation of the acoustic section of the setup.

The whole system is controlled by three microcomputers, developed by the author of the paper, based on Intel i80196KB single-chip microcontroller.[7]

To provide efficient operation and control, the microcomputers are joined into a local network. This allows one to control the setup and perform recording using a personal computer connected to the system through the serial communication port with RS–232 interface. We used a Notebook computer in our measurement sessions.

An electronic section of the setup consists of three similar units, each including three functional microcontrollers, controllers of ultrasonic sensors, and secondary power supply with a modem. The unit structure is shown in Fig. 3. The processor units are similar to that described in Ref. 6, differing only in software. The detailed description of the electronic section is given below.

The Intel i80196KB microcontroller outperforms the processors, which we used earlier, by more than six times. In particular, it has more developed interrupt handler, thus allowing three-task real-time operation of the meter. The first (basic) task is the wind velocity and temperature measurement with four acoustic sensors. The next two tasks (information input and output) are interrupt driven by the microcontroller's receiver and transmitter, respectively.

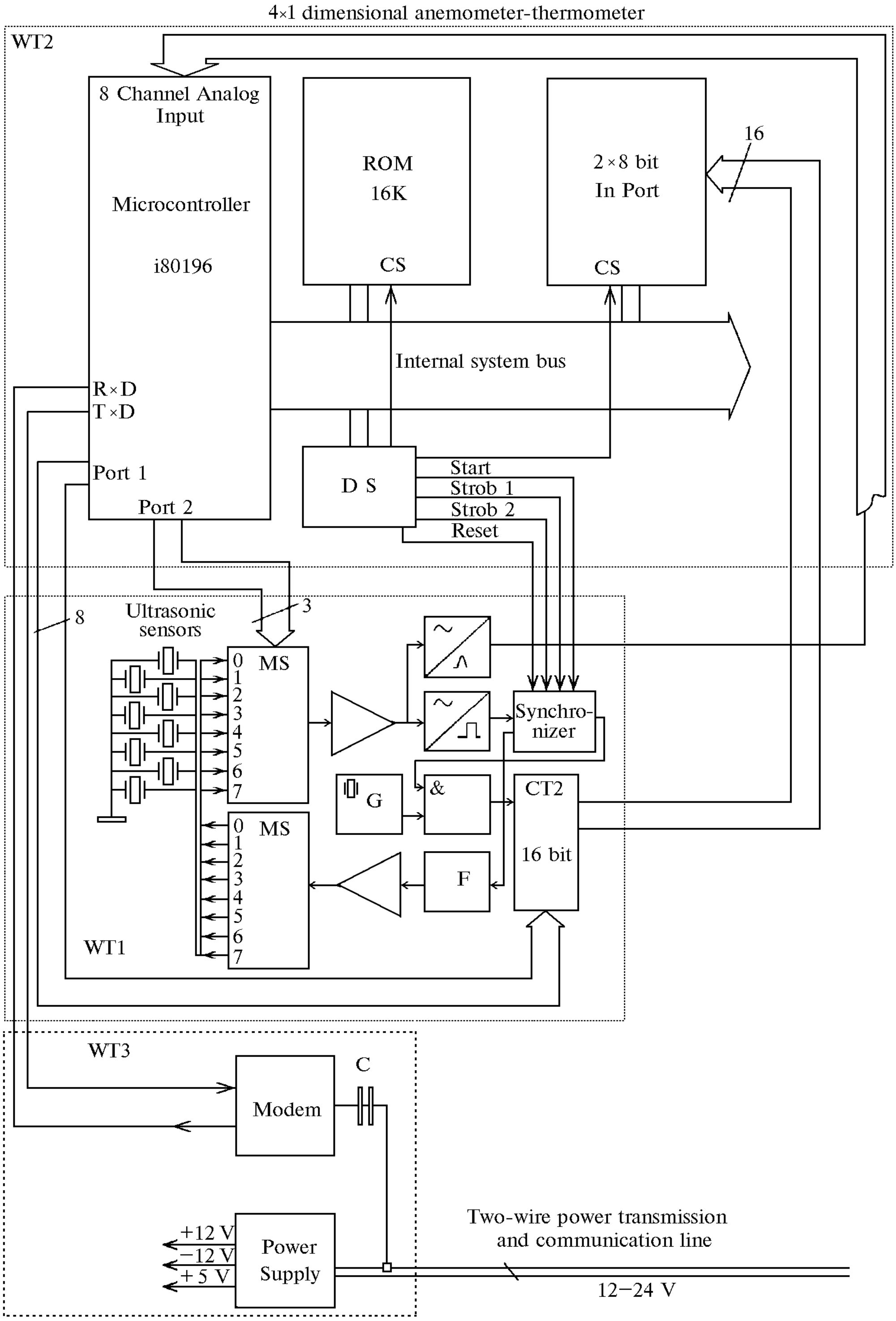

FIG. 3. Block diagram of the electronic unit of the setup.

These tasks use the algorithm, which makes their execution "transparentB for the basic task. The total time consumed by these tasks do not exceed 20 μs per one cycle of measuring the time of one acoustic pulse propagation. The measurement process is thus practically continuous, what is very important when using the phase method of measurements. So, due to absence of breaks in the measurements, we have improved the system operation stability at gusty wind and strong temperature fluctuations. Recall that the system operates in the mode of acoustic signal phase tracking, and it is very important to minimize the measurement period.

All the three microcomputers operate in one network. Each of them has its uniCue network number and responses only to the reCuests addressed to it. The only exception is the common command “fix the data.B By this command, all devices connected to the network place the current values into the output buffer and continue the measuring process.

Then the data are transmitted in turn upon reception of addressed commands “output the data.B Data arrays are stored first in RAM and then on a control computer hard disk. Instantaneous values of the wind velocity field and temperature are thus fixed simultaneously.

The controllers of ultrasonic sensors have been specially developed. They are identical, so we consider here one of them. It consists of time-to-code converter, synchronizer, receiver and transmitter amplifiers, two multiplexers, comparator, amplitude detector, and crystall-controlled oscillator.

The 16-bit time-to-code converter is built upon four synchronous counters with parallel recording the code of starting count. It provides for synchronous counting of time Cuanta, each 20 ns length.

The synchronizer serves to synchronize the controller operation, as a whole, during the measurement cycle. The oscillator generates clock pulses at a stable rate to provide for the time Cuanta of 20-ns length.

The two 8-channel multiplexers are responsible for the choice of the working ultrasonic receiver-transmitter pair.

The secondary power sources have no peculiarities. They are developed in order to reduce the total power consumed. This is very important for remote measuring devices supplying through a twisted pair of the field cable. The pulse sources of the secondary power, manufactured by Nimic-Lambda Inc. (Japan) with the efficiency no less than 95%, are used for this purpose.

All 12 measuring channels operate independently, so it is sufficient to consider the operation algorithm of only one of them. An application of the phase method in measurements reCuires the known initial conditions: the air temperature and the wind velocity. The previous setups[6,7] used individual transmitters of average values of the meteorological parameters for this purpose. The setup under observation is the first one which measures the initial conditions by the acoustic method without additional sensors.

To this end, the amplitude detector is introduced into the receiver’s signal channel and the software is specially developed to determine the initial conditions by the time method. The device does not use a high-speed ADC and buffer RAM, therefore the algorithm implements the method of multiple sensing with increasing time lag. The programmable oscillator with the minimal time Cuantum of 1.377 μs is used as a lag timer.

The accuracy of measurements by this method is not high (± 0.7 m/s for the wind velocity and ± 1.9° for the air temperature), but it is sufficient for the phase method because one period of the working freCuency (40 kHz) corresponds to ± 19° and 12 m/s with the 120-mm measuring base.

The main measuring procedure is the following. The code, inverse to the code of the time, during which the acoustic pulse propagates between two opposite sensors, minus the time eCual to 180° of acoustic pulse phase, is written into the synchronous counter. Then one sensor emits the acoustic pulse, and the synchronous counter receives a permission to start timing. Upon counter overflow, the signal is permitted, by the transfer signal, to come from the receiver’s comparator to the count-stop trigger.

When the signal from the comparator changes its value from unity to zero, what corresponds to the acoustic signal phase of 0°, the oscillator stops the generation of clock pulses. The time code thus assigned to the counter corresponds to the increment in the time of acoustic pulse propagation. It may be both positive and negative, and then it is used in the following measurement as a correction.

The electronic unit uses the up-to-date high-speed digital CMOS RAM manufactured by National Semiconductor. The amplifiers and comparator use the chips produced by Siliconics, Inc. and Maxim Integrated Products, Inc.

The setup was tested under field conditions in May of 1998. The ultrasonic measuring unit was arranged in such a way that the u-axis was directed along the wind velocity, the Y-axis was directed transverse to it, and the Z-axis was directed vertically. Apparently, the longitudinal wind velocity component was recorded. Some examples of time series of the wind velocity and air temperature are shown in Fig. 4.

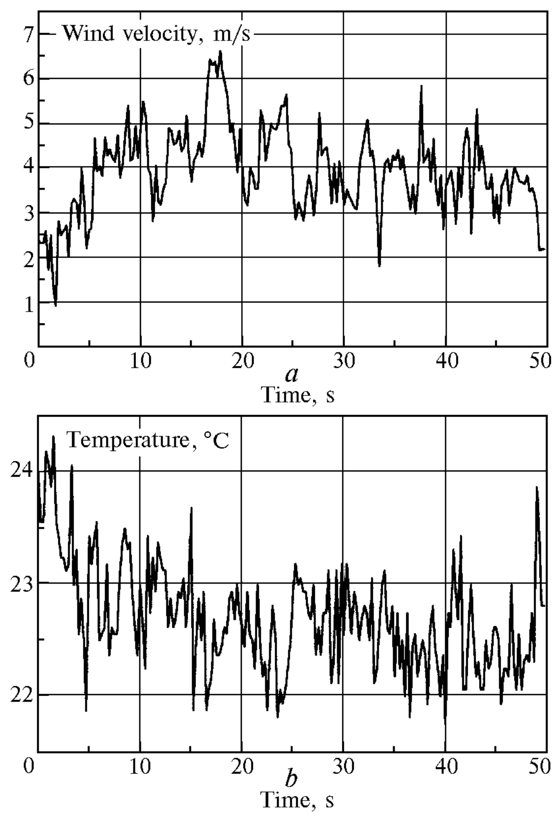

FIG. 4. Time series: wind velocity (a) and the temperature measured by the u 1 sensor (b).

Figure 5 shows the auto-spectra of the temperature and wind velocity fluctuations measured by a sensor arranged along the u-axis. It is clearly seen that the setup is practically noiseless (the characteristic bend in the high-freCuency spectral range is absent) and the curve's slope is eCual to −5/3, i.e corresponds to the Kolmogorov law.

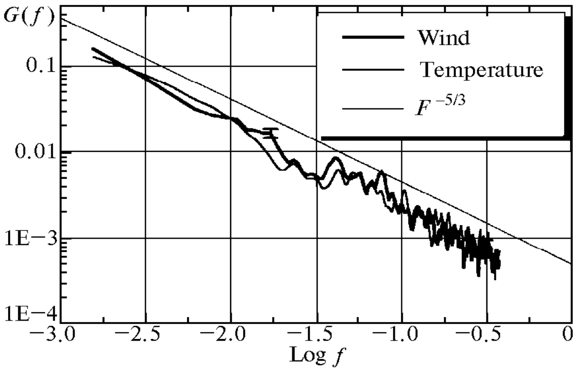

FIG. 5. Spectra of wind velocity and temperature fluctuations measured by the u 1 sensor.

Figure 6 shows the time correlation functions of wind velocity at different distances between sensors along the *u*-axis.

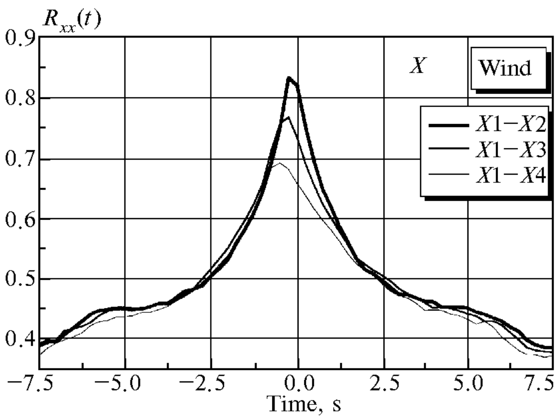

FIG. 6. Time correlation functions of wind velocity along the u-axis.

Figure 7 shows the spatial correlation functions along the *u*-axis (along the wind).

The spatial anisotropy of the wind velocity and temperature fluctuations is clearly seen, what validates the high resolution of the setup.

In 1999 we plan a series of experiments with this setup at the acoustic meteorological station in order to study in detail the spatiotemporal characteristics of vertical and horizontal components of the temperature and wind velocity fields.

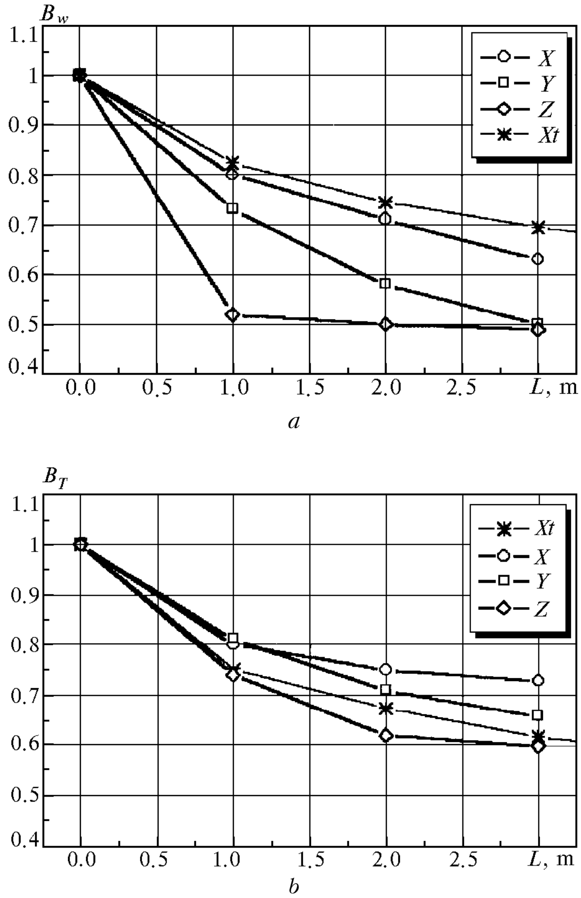

FIG. 7. Spatial correlation functions: wind velocity (a) and temperature (b). The functions calculated from the temporal correlation and the wind velocity are marked with asterisks.

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