MICROBAROMETER IN A VIRTUAL SYSTEM

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Key words: Virtual instruments, microbarometer, data acquisition systems, signal processing

Abstract: A new virtual system for the detection of small pressure variations in the infrasound band of the characteristic Bora wind from the North Adriatic coast has been developed. It is composed of a precision pressure transducer (PPT), standard data acquisition (DAQ) card and virtual instruments (VIs) in the LabVIEW environment. Data collection and analysis of small atmospheric pressure variations during the Bora need a unique pressure sensor and signal conditioning electronics. We have fulfilled several major requirements of the measuring system: sufficient frequency bandwidth (0 Hz to 20 Hz), the resolution of the PPT response and low-noise design, a changeable and adjustable graphic user interface, configurability of the system, and analytical tools for data elaboration. Sufficient linearity is obtained by appropriate selection of a PPT with a signal conditioning circuit. Several efficient methods for the reduction of noise in electronic circuits have been used. The best effect in signal conditioning is achieved with low-noise electronic components, an appropriate circuit layout, and correct cabling and ground connection. Signals generated in the PPT are conditioned, acquired and analyzed under the control of a particular virtual instrument (VI) and subinstruments (subVI). DAQ and analysis are supervised from the front panel of a particular VI. The principal aim of the data analysis is the power density function (PDF) obtained with certain complex virtual VIs. The custom-designed Power Spectrum Analyzer (PSA) VI offers many useful options: graphical presentation of time and frequency, data records selection, changeable windowing and measurement of noise level.

Mikrobarometer v virtualnem sistemu

Kjučne besede: Virtualni instrumenti, mikrobarometer, sistemi za zajemanje podatkov, procesiranje signalov

Izvleček: Delo opisuje virtualni sistem za zaznavanje in merjenje majhnih sprememb zračnega tlaka. Merjene spremembe povzroča burja, ki je značilen veter severnega Jadrana. Merilno napravo sestavlja precizen senzor tlaka, standardna večfunkcijska kartica za zajemanje podatkov in virtualni instrumenti v programskem okolju LabVIEW. Zbiranje in analiza podatkov o spremembah zračnega tlaka, ki jih povzroča burja, zahteva poseben senzor tlaka in elektronsko vezje za prilagajanje signalov. Realizirani sistem izpolnjuje vse glavne zahteve merilnega sistema: ustrezen frekvenčni pas (0 Hz do 20 Hz), ločljivost preciznega senzorja tlaka in malošumna izvedba vhodnega vezja. Poleg tega načrtovani sistem omogoča spremenljiv in prilagodljiv uporabniški vmesnik, fleksibilno zgradbo sistema in analitična orodja za obdelavo podatkov. Linearnost odziva smo dosegli s primernim senzorjem in vezjem za prilagajanje signalov. Zmanjšanje šuma smo dosegli z uporabo metod načrtovanja malošumnih vezij. V vezju za prilagajanje signalov smo uporabili malošumne elektronske komponente, primerno načrtovano tiskano vezje ter pravilne medsebojne povezave in povezavo mas. Signali, ki jih generira senzor se prilagajajo, zajemajo in analizirajo pod nadzorom načrtovanega virtualnega instrumenta (VI) in virtualnih podinstrumentov. Zajemanje podatkov in analizo lahko spremljamo prek čelne plošče določenega VI. Glavni cilj analize podatkov je izračun in prikaz funkcije gostote močnostnega spektra, do katere pridemo z gradnjo kompleksnih VI. Zgradili smo uporabniško orientiran VI "analizator močnostnega spektra", ki nudi več uporabnih funkcij: grafično predstavitev spektra v časovnem in frekvenčnem prostoru, izbiro podatkovnega niza, izbiro okenske funkcije in meritev šumnega nivoja.

1 Introduction

Infrasound is inaudible sound with frequencies below the human hearing threshold of 20 Hz. The lower frequency cut-off of infrasound is limited by the thickness of the atmosphere. In general, infrasound is measured within a frequency range of 0.005 (T=200 s) to 20 Hz (T=50 ms). Within this frequency band, many sources of both known and unknown origin generate infrasound. Sources that can often be detected for seconds, minutes or hours are: winds, volcanoes, sea waves, explosions, meteors, mountain-associated waves and aurora. Infrasound can be measured with either a low-frequency microphone or a high-frequency barometer. In the project we preferred the use of a microbarometer because of its robustness with respect to field application and durability. Furthermore, microbarometers can measure much longer periods than microphones.

Measurements of small and rapid variations of atmospheric pressure have historically been made by a variety of methods. All of them are enabled by means of different types of pressure transducers /1/ connected to data acquisition, elaboration and storage systems. Standard analog barometers have resolutions in the range of hPa (or mb). Precise measurements of atmospheric pressure changes are made with microbarometers with resolution in the range of 0.1 hPa to 0.002 hPa /2/, /3/. Such instruments are suitable for observation of fluctuations of the pressure of the wind. The Bora in the Karst region (Kras, Carso) is a particular type of wind in which the energy peaks are pulsations. They are of particular interest because they disappear and reappear within an episode /4/. Spectral analysis of the Bora reveals information about energy content, time distribution and local characteristics.

A better understanding of the principal physical characteristics of the Bora provides a key to solving local problems in the areas of construction, architecture, environmental planning, agriculture, traffic control, etc. This can lead to cost reductions and an increase in the quality of life. A preliminary spectrum analysis was carried out on patterns of atmospheric pressure oscillations generated by the Bora, as recorded in Trieste (Italy) /5/.

Bora wind gusts produce immediate changes of pressure that the pressure transducer has to convert proportionally to a voltage. A microbarometer with a very accurate, stable and sensitive built-in pressure transducer is needed for such purposes. Some commercially available pressure transducers match the specifications for accurate continuous measurements of instantaneous atmospheric pressure changes. The microbarometer employed uses a high-accuracy pressure transducer system made by Setra Systems Inc. /6/and /7/. The PPT is connected to a custom-designed circuit which performs conditioning of the analog signal.

All measurements of low-level signals are subject to noise. Various methods describe the reduction of noise in signal conditioning circuits, but they are difficult to implement in practice /8/. With regard to noise, there are some significant factors, among which the most influential are grounding, shielding, proper ground connection and suitable circuit layout strategy. On the other hand, there are several methods for lowering noise in the measuring signal. The most well known is analog filtering, which is always used in antialiasing circuits. Another method is averaging, which can be performed in hardware or in the software of the measuring system.

The analog signal terminates in a DAQ system. Many standard PC-compatible plug-in DAQ cards offer many advantages in comparison with classic measuring instruments. Today's multifunction cards are reliable, accurate and cost effective. Moreover, they use plug-and-play technology and are compatible with the Windows operating system and with most software packages designed for building VIs. General purpose VIs, such as multimeters, function generators and oscilloscopes, are frequently offered, but special measuring VIs are rarely available on the market.

Choosing the right DAQ card is very important for the design of a measuring system. The selection should be made on the basis of electronic specifications, with close correlation of the card's characteristics and measurement needs. Full hardware compatibility with LabVIEW plays an important role in the final choice of a DAQ card.

A virtual instrument (VI) can be created in the LabVIEW environment. Using VIs, a virtual measuring system can be set up which enables the user to carry out measurements on various subassemblies under specific program control. This kind of instrument has some advantages compared with classical or traditional measuring instruments /9/.

The challenge of the project was to design a VI-based microbarometer for spectral analysis of the Bora. The system must be capable of acquiring samples from the PPT, performing measurements using an appropriate standard DAQ card /10/, and processing and storing the acquired signal. The solution was combining a high-performance plug-in data acquisition card and signal conditioning in order to obtain a precise measurement of wind parameters. The VI enables the user to acquire data from the PPT (located outdoor) and process the data, calculate performance results, log data and generate reports /11/.

2 Transducer unit

Precision pressure transducer

The Precision Pressure Transducer (PPT) is a compact sensor device that generates a very sensitive analog output signal proportional to the pressure being measured. The PPT unit has an analog output and is individually calibrated at the factory for temperature variations over the full scale pressure span across a -40 to 85°C range.

The PPT used is a Setra Systems Inc. Model 270 analog sensor which measures absolute (atmospheric) pressure. It contains a capacitor as a sensing element, which results in a simple, durable and fundamentally stable device. The sensing scheme is presented in Figure 1.

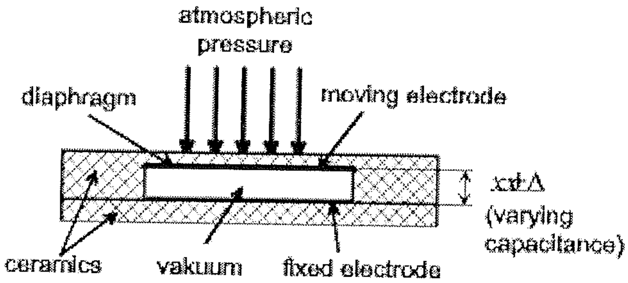

Fig. 1: Cross-section of a capacitive absolute pressure sensor.

In a typical configuration, a compact housing encloses two closely-spaced, parallel, electrically-isolated metallic surfaces. One surface is essentially a diaphragm capable of slight flexing under applied air pressure. The diaphragm is constructed of a low-hysteresis material, such as 17-4 PH SS or a proprietary compound of fused glass and ceramic: Setraceram. These firmly secured surfaces (or plates) are mounted so that a slight mechanical flexing of the assembly D*x*, caused by a change in applied pressure, alters the gap *x* between them to *x* ± D*x* (creating, in effect, a variable capacitor), as depicted in Figure 1.

Capacitive pressure transducers are not common but do have higher sensitivity to pressure changes than do other pressure-sensing devices (typically 10 to 100 times). They are much less sensitive to thermal stresses and local diaphragm stresses since capacitive transducers integrate the movement of the entire surface of the diaphragm, while piezoresistive (PR) and piezoelectric (PE) devices use localized strain measurements. Capacitive transducers commonly have small capacities and generally are more expensive and larger than other devices because they usually carry their signal conditioning circuitry on the same board as the sensor.

The sensor alone is very sensitive to environmental coupling, so it must be mounted in a mechanically and electrically protected space. In the case of Setra's PPT, protection is afforded by a stainless steel housing to cover the sensor and functional electronics (excitation circuit, amplifier, power supply, analog buffer, etc.). To reduce noise and increase the signal-to-noise ratio, the amplifier unit must be located as close as possible to the sensor element.

The capacitance of the sensor is a pure measuring value, so it must not be changed in the remaining circuitry. Signals containing the measurement are conducted to the signal conditioning circuit. The sensitivity of the signal-conducting wires is such that all other conductors need a shield.

3 Data acquisition

The data acquisition (DAQ) unit is an important subassembly with the main functions of conditioning and multiplexing input channels, digitalization of input analog signals, timing control, synchronization and providing a digital I/O port. Usually we consider the DAQ card as a DAQ system, but in this case we must distinguish between the DAQ card and DAQ process. The DAQ process includes the conditioning part of the PPT and relevant software control.

The data acquisition system (DAS) contains two main subunits: signal conditioning and signal conversion. Signal conditioning is partially accomplished by the PPT unit, while the conversion is on the input stage of the DAQ multifunction card. Analog-to-digital (ADC) signal conversion with all the necessary logic and data path circuitry is part of the multifunction DAQ card.

3.1 Signal and data flow

Once an analog signal from the sensor output is achieved, signal conditioning is applied. The main premise of the signal conditioning is linearity and response of the analog signal. After that, signal conversion follows and the data become digital information. The basic scheme of signal and data flow is presented in Figure 2.

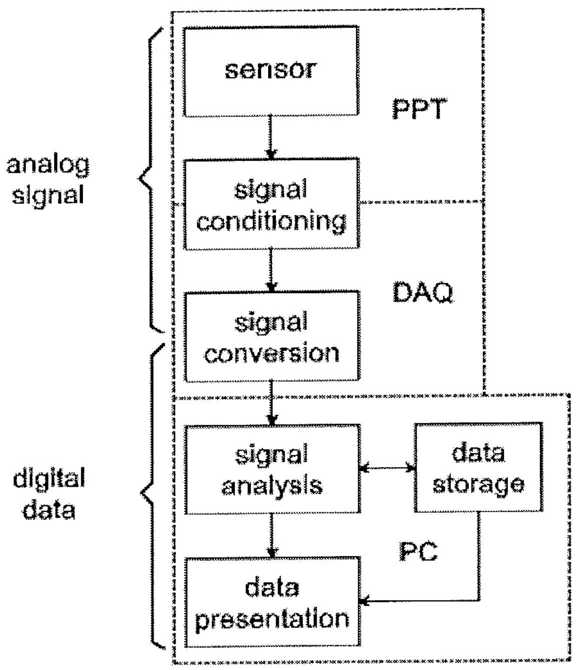

Fig. 2: Signal and data flow from PPT to data storage.

Analog signal flow begins with the PPT as the generator and ends with the ADC. Because of the very low-level signals of the first part of the circuit, they are very sensitive to noise and other disturbances from the surrounding environment.

The signal path is followed by temporary data storage and data elaboration. Under the control of software, suitable data records are created and signal analysis is performed. The virtual system permits the user to observe the results graphically in quasi real time. At the same time, data are stored on two independent memory media for later processing and analysis.

3.2 Signal conditioning

A linear transformation between signal excitation and response must be achieved by the signal conditioning circuit. Components that can be driven to the limits of the supply voltage (rail-to-rail) make the maximum dynamic range available. Signal conditioning is performed in two successive phases: the first phase is accomplished on the sensor unit and the second is performed on the standard DAQ multifunction board.

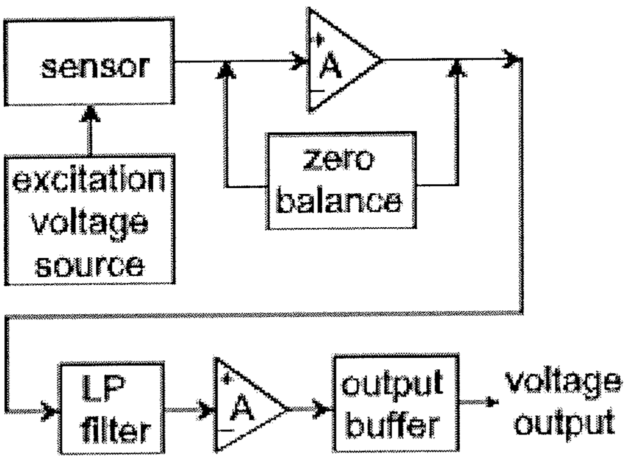

Fig. 3: Signal conditioning circuit.

The main task of the signal conditioning circuit is adequate signal propagation, during which the signal is set to fit the ADC input voltage swing. Signal amplification reduces noise and protects signals from other disturbances. To increase dynamic range in this low-voltage environment, the first operational amplifier A in Figure 3 processes rail-to-rail input signals and drives rail-to-rail output signals. A circuit that maintains constant transconductance g_m over the input common mode ranges reduces distortion. The bandwidth of the signal conditioning circuit must provide a frequency response within the range of interest for the fastest rate of change of the signal.

The antialiasing filter is one of the most important elements of the DAQ system /12/. It is impossible to differentiate between noise with frequencies in the band and out of the band of interest. Only an analog filter can preserve signal integrity and extract real frequencies from folded frequency components. The cut-off frequency of the antialiasing filter must lie below the Nyquist frequency. The method for determining and implementing the appropriate analog filter parameters is controlled using Microchip's "FilterLab" software. The proposed circuit has been exported and simulated by PSPICE (Cadence Inc.) and the result is presented in Figure 4.

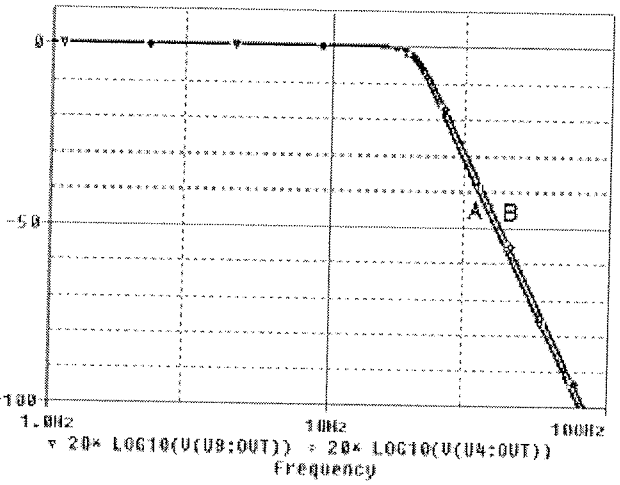

Fig. 4: Calculated (A) and realized (B) transfer function of the antialiasing filter.

Implementation with a Butterworth filter design has been carried out. A Butterworth filter is used in the filter implementation of the antialiasing filter. For this circuit, an 8^{th}-order filter is used with a cut-off frequency of 10 Hz. Four active Sallen-Key filters are used. This filter attenuates the pass band signal to 80dB at a frequency of 20 Hz.

The effect of the filter is clearly visible in Figure 5. The output signal with noise is measured directly in the illustration above and passing the filter stage in the illustration below.

3.3 Signal Conversion

The ADC is an Analog Devices successive approximation register type with a maximum 200 kS/s conversion rate. It operates from a single 5 V power supply. The resolution of the ADC is 16-bit, or 1-in-65536. The converter's integrated circuit contains a high-speed 16-bit sampling ADC, an internal conversion clock, internal reference, error correction circuits, and both serial and parallel system interface ports. The ADC is fabricated using a high-performance, 0.6 mm CMOS processor and is operable from -40°C to +85°C.

The single 5 V supply of the ADC typically dissipates only 35 mW. Its power dissipation decreases with throughput to, for instance, only 15 μW at a 100 SPS throughput. It consumes 7 μW maximum when in power-down mode. The circuit has superior integral nonlinearity (INL). A maximum

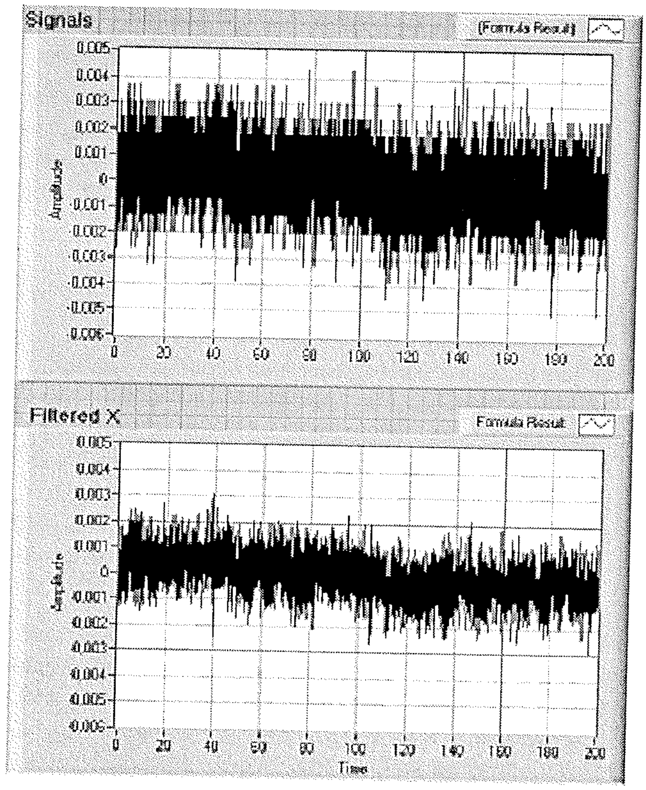

Fig. 5: Output noise level of the output signal without (above) and with filtering (below).

INL of 3 LSB with no missing 16-bit code is achievable. Serial or versatile parallel interfaces (8 bits or 16 bits) or a 2-wire serial interface arrangement compatible with both 3 V and 5 V logic are available.

Conversion is also possible in burst mode as a software-selectable option at a burst rate of T = 5 μs. The ADC uses a RAM buffer which holds 8 K samples. Data transfer can be programmed input-output (I/O) or direct memory access (DMA). DMA modes are "demand" or "non-demand" using scatter/gather operations. Configuration memory contains up to 8 K elements, which can be stored data for channel programming, gain, and offset of the on-board signal conditioning circuit. Maximum sampling rate reaches 200 kS/s with single channel operation and a 15-minute warm-up. Accuracy is assured by internal calibration. Measurements are valid for operational temperatures within ±1 °C of internal calibration temperature and ±10 °C of factory calibration temperature.

All hardware configuration options on the multifunction card are software controlled. Some configuration options, such as digital channel configuration (input or output), have been configured with installation software (InstaCal). Once selected, any program that uses the Universal Library can initialize the hardware according to these settings.

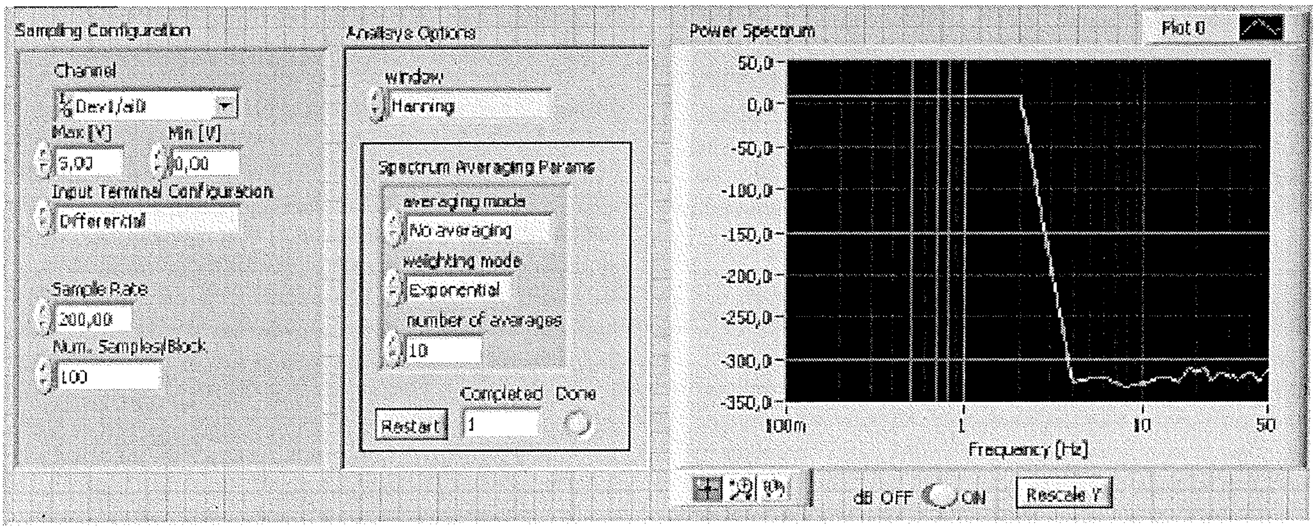

Fig. 6: Front panel of power spectrum VI.

4 Virtual instrument for data acquisition and analysis

4.1 Configurability and design of the system

One of the goals of the project was the design of a virtual system controlled by a VI. This permits a very flexible configuration with possibilities of choosing or changing various parameters and settings. Combining of different subVI hardware and software operations can also be performed, plus complex mathematical operations involved in signal analysis.

With the VI, the average power spectrum of an input signal in the time domain can be computed. Various averaging modes for measurement have been tested, such as RMS averaging, vector averaging, or peak hold, as well as the number of averages. The number of averages influences the noise floor. Vector averaging requires the use of a trigger in order to lower the noise floor without lowering the fundamental signal along with it. VI has various filter selections, where the type of window used in the particular measurement can be selected.

Once all properties of the system were known and defined, two-pass top-down software design started. Initially, a front panel was created. Functions were added and tested successively, continually being aware of the main goal. An example of the front panel of power spectrum VI is presented in Figure 6.

The supervisory part of the software was built in the second pass of the design process. The block diagram responsible for program execution contains primitives and subVIs. The block diagram for wind analysis data is conceptually created with DAQ control and an analytical part.

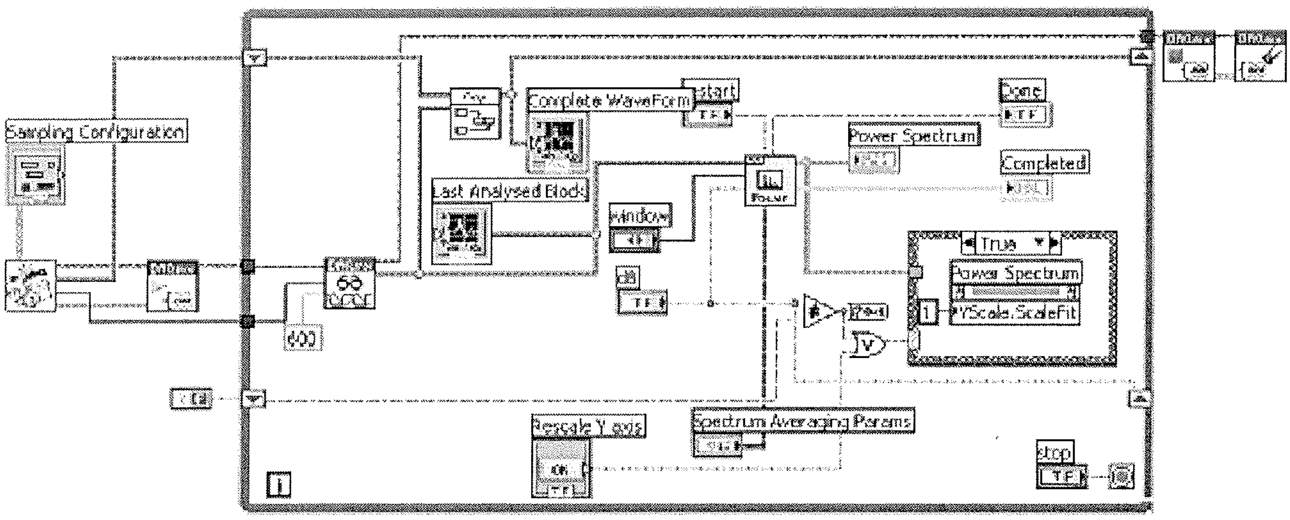

Fig. 7: Partial block diagram of the power spectrum VI.

The control part manages the system hardware. It contains various settings to optimize acquisition parameters and visualization of data. The Functions menu of LabVIEW's analysis module offers all the useful operations and procedures needed to assemble a signal analysis VI. We used several suitable subVIs to facilitate and speed up the design process. A view of a part of the block diagram created as a power spectrum VI is presented in Figure 7.

4.2 Signal analysis and data presentation

The main objective of the analysis is to determine the spectral composition of the observed signals of pressure fluctuations in order to determine characteristic features as a function of weather conditions, in particular of wind direction and speed.

It has been assumed that the observed signals result from a superposition of low-frequency waves (with a range of time periods extending from several minutes to several hours) and higher-frequency waves. Overall power is the sum of the contribution of each component. PSD was estimated using a built-in Fast Fourier Transform (FFT) algorithm. Despite the limitations implicit in the limited frequency resolution and the power "leakage" which results from data windowing, this method is computationally efficient and obtains reliable results for a wide range of processes.

A LabVIEW-based computer program (VI) was developed for spectral analysis of large data samples. Data records were segmented into time intervals corresponding to the duration of the analyzed phenomenon. The most interesting data samples can also be presented on a graphic interface over time. Our analysis succeeded in the following steps:

a) trend removal,

b) low and high frequency limit,

c) estimation of power spectral density.

For the proper data presentation one has to know and understand the physical phenomena and the origin of the acquired data. There are several sources which determine the micro-fluctuations of atmospheric pressure extending over a wide range of frequencies (which may involve several orders of magnitude). Among them are frequently observed global and local configurations of the earth's surface. The Bora is a typical dry wind from the Julian Alps, characterized by strong gusts (over 50 m/s) blowing over the Karst and the Gulf of Trieste, predominantly in winter. It also reaches the surrounding countryside, but in a weakened form. The analysis refers to samples of Bora wind recorded in Trieste on a windy day over a time span of six hours.

An example for the verification of system operation is the data acquisition system registering pressure fluctuations on the PPT with sampling rate of 100 samples/s. Upon removal of linear and seasonal trends, a low-pass filter (by means of a moving-average model) was applied to the data.

Data elaboration was carried out by various LabVIEW subVI's found in the Mathematics & Statistics module.

On windy days, thunderstorms can also very frequently occur. Such cases present an additional source of noise, i.e. atmospheric noise. Atmospheric noise is a non-stationary process that introduces non-regular disturbances in the measuring signal. Detection and elimination of this kind of noise will be the task of our further work.

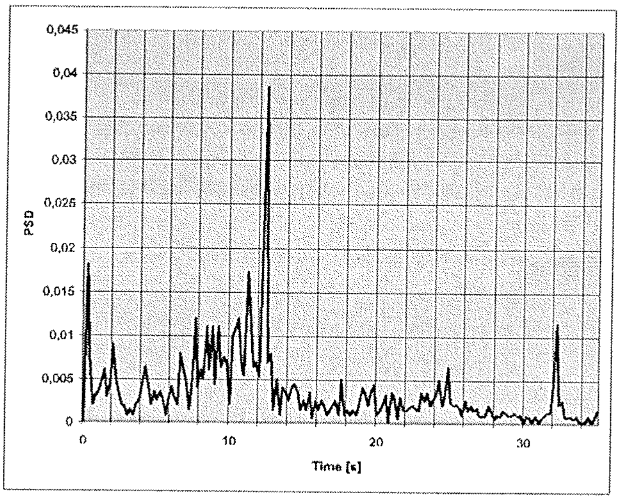

Fig. 8: Power spectral density of the Bora in the Gulf of Trieste.

The results of spectrum analysis carried out using the FFT method is presented in Figure 8. Frequency-to-time transformation of the PSD was used to facilitate physical interpretation of the phenomena. The analysis demonstrates the existence of notable features during peak force of the wind (a period of approximately 12 seconds). These results also agree with recent measurements made by Belusic et al. /4/ as well as observations conducted over fifty years ago by Mosetti /5/using a classical mechanical microbarograph.

5 Conclusions

The characteristics of the Bora wind can be observed using a microbarometer. The availability of powerful, low-cost microprocessors and memory has eased the task of designing the signal processing necessary for high-performance air data collection. Even with the sophisticated digital signal processing provided by microprocessors, the performance of air data instruments is still strongly dictated by pressure transducer characteristics: basic accuracy, resolution, long-term stability and reliability over the spectrum of environmental conditions encountered in ecological investigations.

Digital-output pressure transducers have on-board ADCs, which, all else being equal, provide higher performance and easier integration of air data measurements into PC analysis and the presentation environment.

The usage of a suitable sensor and a particular electronic arrangement leads to substantial noise reduction and offers the ability to determine source characteristics such as apparent PSD and RMS noise. A VI with a graphical user interface enables the configuration of important features of acquisition and analysis, so that various types of winds, which all cause instantaneous variations of pressure, can be distinguished. This offers a new, simple, intuitive front-panel user interface with versatile functionality. The data acquisition of very low pressure changes is applied as a monitoring technique for determination of wind characteristics. The processing and interpretation of pressure micro-variation recordings has been illustrated with data from the Gulf of Trieste. Current research efforts are concentrated on hardware and software improvements: integration of micro-controlled signal conditioning and conversion electronics on board, further reduction of noise on the analog signal path, wireless digital data transmission and web integration of the virtual system.

With the LabVIEW program users can create a PPT-interface VI with custom capability for both single PPT and use with a DAQ card. Users can easily set up an interface to the PPT for establishing communication, issuing commands, configuring the device, charting data in real time and storing data to text files. This project also demonstrated the usage of the LabVIEW program for creation and utilization of more complex programs. Software development in a graphical environment can be quickly understood and it is easy to use. VI proves to be the optimal solution for projects where a nonstandard instrument or a particular measuring environment is needed.

By employing VIs, many advantages have been achieved. Firstly, the cost of the system, using various subunits, is very low. Secondly, development time is short, enabling immediate use of the system. Thirdly, system maintenance expenses are lower, involving the PPT and DAQ card only. A very simple hardware configuration also elevates the quality of the research. We have achieved excellent accuracy, reliability and stability in a virtual measuring system.

6 References

/1/ The Pressure, Strain and Force Handbook, Vol. 28, *Omega Engineering, Inc.*, Stamford, 1992.

/2/ Richiardone, R. and Manfrin, M. (2002): A Rain Episode Related to a Mesoscale Gravity Wave during MAP. *Preprints volume of the 10th Conference on Mountain Meteorology American Met. Soc.*, Boston, 213-214.

/3/ Digiquartz Pressure Instrumentation: Features, Quality and Standards, *Paroscientific Inc.*, 4500 148th Av. N.E. Redmond, WA 98052 USA, www.paroscientific.com, Date: Aug. 11th, 2006

/4/ Danijel Belušić, Miroslava Pasarić, Zoran Pasarić and Mirko Orlić, The Dynamics of Pulsations in the Bora Flow, *University of Zagreb*, Zagreb, Croatia

/5/ M. Ceschia, G. Iob, Spectral estimates of the surface pressure fluctuations associated with the "bora" wind recorded in Udine and Trieste, *Proc of the 6th International Meeting on Statistical Climatology*, 19-23 June, 1995, University College, Galway, Ireland, pp. 621-624

/6/ SETRA Model 270 Specifications, SSP270 Rev.C 04/19/01, 159 Swanson Road, Boxborough, MA, USA, www.setra.com, Date: August 23rd, 2006

/7/ Operating Instructions Model 270 Pressure Transducer, Rev. D 6/98, SETRA, 159 Swanson Road, Boxborough, MA, USA, www.setra.com, Date: August 23rd, 2006

/8/ Henry W. Ott, Noise Reduction Techniques In Electronic Systems, 2nd Ed., *John Wiley & Sons*, New York, 1988

/9/ Using LabVIEW with Honeywell's Precision Pressure Transducer (PPT), AN-105 (Preliminary), *Honeywell Inc.*, www.ssec.honeywell.com, Date: July 20th, 2006

/10/ PCI-6013E/6014E User Manual, *National Instruments Corporation*, Part Number 322072C-01, December 2000

/11/ Robert H. Bishop, LabVIEW Student Edition 7i, *Prentice Hall*, Upper Saddle River, NJ 07458, 2001

/12/ Bonnie C. Baker, Anti-Aliasing, Analog Filters for Data Acquisition Systems, AN-699, *Microchip Technology Inc.*, 1999

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