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Virtual Multisensors Data Acquisition and Analysis System Design

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Introduction

The concept of virtual instrumentation was born in late 1970s, when microprocessor technology enabled a machine's function to be more easily changed by changing its software. Virtual instrumentation combines mainstream commercial technologies, such as the PC, with flexible software and a wide variety of measurement and control hardware, so engineers and scientists can create user-defined systems that meet their exact application needs.

Virtual instrumentation refers to the use of general purpose computers and workstations, in combination with data collection hardware devices and virtual instrumentation software, to construct an integrated instrumentation system [1–3]. In such a system, the data collection hardware devices are used to incorporate sensing elements [4] for detecting changes in the conditions of test subjects. These hardware devices are intimately coupled to the computer, whereby the operations of the sensors are controlled by the computer software and the output of the data collection devices are displayed on the computer screen with the use of displays simulating in appearance of the physical dials, meters, and other data visualization devices of traditional instruments [5–7]. For example, increasing number of biomedical applications use virtual instrumentation to improve insights into the underlying nature of complex phenomena and reduce costs of medical equipment and procedures [8]. Virtual instrumentation systems also comprise pure software "instruments," such as oscilloscopes and spectrum analyzers, for processing the collected sensor data and "messaging" it such that the users can make full use of the data.

The Internet has enormous potential for distributed virtual instrumentation [9]. Various remote devices, such as telerobots or remote experimental apparatus, can be directly controlled from the Internet. There are a great number of research activities that explore how the Internet can be applied to medicine. In addition, many of virtual instrumentation development tools, such as LabView [10], directly support integration of virtual instruments in the Internet environment. The Web technologies make possible creation of sophisticated client-server applications on various platforms, using interoperable technologies such as HTML, Java Applets, Virtual Reality Modeling Language, and multimedia support.

Recently developed digital sensors integrated on singular chip have some important features as small dimensions, enhanced response rate, high reliability, stable response with negligible dispersion of the transfer characteristics from device to device and performance to enable good commuteability [1, 5]. Due to these features, the total costs of a system development, realization and maintenance are significantly reduced. However, the price ratio of the digital sensors and the appropriated analogue sensors is still relatively high on the market.

The virtual system proposed in this paper is based on the IBM compatible PC and the simple microcontroller's interface with integrated digital temperature, humidity and ambient light sensors and an analogue atmospheric pressure sensor. The system is designed for more laboratory setup. A special care is dedicated to the user software designing whose features have the direct influence on the solution quality. The user software is realized under LabView IDE.

Such concept enables compact measurements, recording and analysis more quantities simultaneously as well as easily sensors replacement without the need of calibration.

Hardware arrangement

The central part of the acquisition hardware is the Microchip microcontroller PIC18F4550 with built in the USB periphery. The Dallas DS18B20 one-wire digital thermometer serves for internal air temperature monitoring while the SHT11 digital multi sensor module collects the information as the external air temperature and relative air humidity. Ambient light-to-digital sensor TSL2550 (TAOS) is used for light level monitoring and to determinate kind of the light. An analogue absolute pressure sensor MPX4115A (Motorola) is connected to analogue channel AN0 of the microcontroller A/D module working in oversample mode with 12 bit’s resolution per sample.

Complete scheme of the system hardware is showed in Fig. 1. As shown in Fig. 1. communication between the acquisition hardware and PC is established via galvanic isolated USB port of the PC or precisely by emulating RS232 over USB. The communication device class (CDC) specification defines many communication models including serial emulation. This is necessary because the LabView 7 Express software has not embedded functions for USB control transfer. Simultaneously, the galvanic isolated power lines of the PC’s USB port serve as power supply lines of the acquisition hardware. In this way, the acquisition hardware becomes independent on the external power supply sources. Two buttons in the scheme serve for in-circuit serial programming of the microcontroller on the base of stand-alone USB bootloader program.

As can be seen in Fig. 1 the microcontroller is clocked by 20MHz crystal resonator. Precisely sampling time of one second is generated including RTC functionality of the 16-bit timer/counter TMR1 by adding an external LP watch oscillator. An overflow of the TMR1 register causes a TMR1 overflow interrupt (if enabled). The interrupt service routine can then perform the appropriate task.

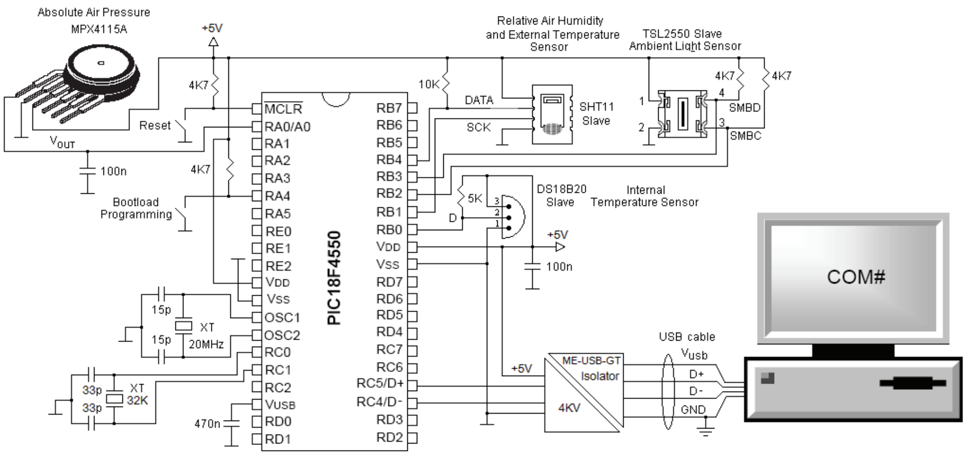

Fig. 1. The acquisition hardware and PC as hardware of the system

The DS18B20 digital thermometer [5] provides 9-bit or 12-bit programmable resolution temperature readings. The temperature data is stored as a 16-bit sign-extended two’s complement number in the temperature register.

The SHT11 is a single chip relative humidity and temperature multi sensor module [1] comprising a calibrated digital output. The device includes a capacitive polymer-sensing element for relative humidity and a bandgap temperature sensor. Both are seamlessly coupled to a 14 bit analog to digital converter and a two wire serial interface circuit on the same chip. Each SHT11 is individually calibrated in a precision humidity chamber with a chilled mirror hygrometer as reference. The calibration coefficients are programmed into the OTP memory. These coefficients are used internally during measurements to calibrate the signals from the sensors. The two-wire serial interface is optimized for sensor readout and low power consumption and is not compatible with standard I^2C interface. The chip includes heater for condensation prevents in high RH environments (>95 %RH). The 'End of Battery' function detects supply voltage drops below 2.47V for battery operation. The default measurement resolution of 14 bit (temperature) and 12 bit (humidity) can be reduced to 12 and 8 bit, respectively. This is especially useful in high speed or extreme low power applications taking into account shorter conversion time of the measurement quantities.

Table 1. Status register content of the multi sensor module SHT11 (Sensirion)

Bit	Type	Description	Default	
7		reserved	0	
6	R	End of battery 0 for V_{DD}>2.47V 1 for V_{DD}<2.47V	x	No default value.
5		reserved	0	
4		reserved	0	
3		For test only, do not use	0	
2	R/W	Heater	0	Off
1	R/W	No reload from OTP	0	Reload
0	R/W	1=8bit RH/12bit Temp. 0=12bit RH/14bit Temp.	0	12bit RH/14bit Temperature

Table 1 shows the content of the 8 bit status register of the SHT11. By programming the status register we select some of above mentioned functions.

By the manufacturer specifications (Sensirion), typical response time of the humidity sensor is 4s and for temperature sensor about 30s. Average conversion time amounts 11/55/210 ms for a 8/12/14 bit measurement, respectively. For a peak measurement resolution the temperature resolution is 0.01 ^{0}C and for humidity 0.03 %RH. For nonlinearity compensation of the sensors responses and for temperature compensation of the humidity the manufacturer offers polynomial functions for digital outputs conversion to the physical values [1]. In such a way full specified accuracy can be achieved. Since humidity and temperature are booth measured on the same monolitic chip the SHT11 allows superb dew-point measurements.

Ambient light-to-digital sensor TSL2550 (Taos) is designed for use with broad wavelength light source. One of the photodiodes is sensitive to visible and infrared light, while the second photodiode is sensitive primarily to infrared light. The ADC digital outputs of the two photodiodes are used to obtain a value that approximates the human eye response in the commonly used unit of Lux. The SMBus serial interface is optimized for sensor readout. ADC data format is shown in Table 2. The sensor can discriminates the type of light (sunlight, fluorescent and incandescent light). More details about the sensor offers the manufacturer.

Table 2. ADC data format for TSL2550 light sensor

Valid	CHORD BITS			STEP BITS			
B7	B6	B5	B4	B3	B2	B1	B0
Valid	C2	C1	C0	S3	S2	S1	S0

Motorola's MPX4115A silicon pressure sensor integrates on chip bipolar op. amplifier circuitry and thin film resistor networks to provide high output signal and temperature compensation. Fig. 2 shows the sensor output signal relative to pressure input.

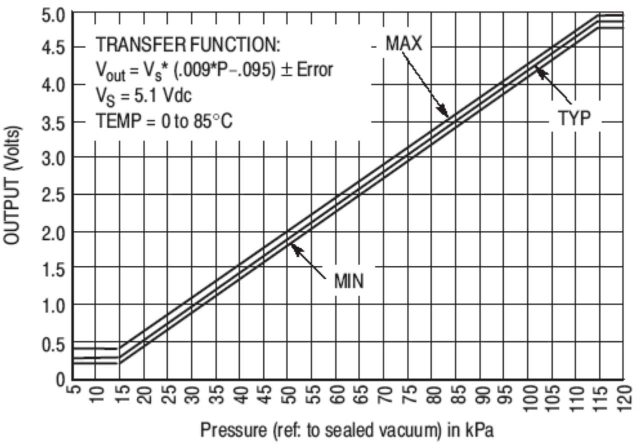

Fig. 2. Transfer characteristics of the MPX4115A

Typical minimum and maximum output curves are shown for operation over 0^0C to 85^0C temperature range. The output will saturate outside of the rated pressure range.

The microcontroller's firmware is written using CCS C compiler IDE version 4.057. The program includes procedures of the microcontroller's peripherals initialization, interrupt service routine, one-wire and specific two-wire protocol for communication with sensors and USB CDC API for virtual COM port creating. The system firmware starts or stops program execution after received appropriate string from the PC. By comparison the received string with the adopted start and stop string constants within the interrupt service routine the microcontroller resolves appropriate PC request.

Graphical user interface

The user software is realised under *Windows* operating system which ensure quality graphical environment, multitasking and interaction between graphical user interface objects and appropriated subroutines (event-driven principle). The LabView software (*National Instruments-USA*) [10], as leader in virtual instrumentations domain, is used to realization our project.

LabView is a graphical programming development environment based on the G programming language for data acquisition and control, data analysis and data presentation. LabView gives the flexibility of a powerful programming language without the associated difficulty and complexity because its graphical programming methodology is inherently intuitive to programmers. With LabView the user can control own system and present results through interactive graphical front panels. On the front panel user places the controls and data displays for own system by choosing objects from the controls palette including numeric displays, meters, gauges, LEDs, charts, graphs and more. To program, programmer constructs the block diagram by choosing objects (icons) from the functions palette and connect them with wires to pass data from one block to the next. These blocks range from simple arithmetic functions, to advanced acquisition and analysis routines, to network and file I/O operations. Therefore, LabView uses a dataflow programming model, so called G, that frees programmer from the linear architecture of text-based languages.

The realized GUI at on-line mode is shown in Fig. 3. Five of six real time waveform charts are physical channels while the last dew-point waveform is arithmetic channel. Digital indicators on the charts show instantaneous values of the physical quantities as well as the displays for pressure altitude and light type preview. Above mentioned polynomial functions for SHT11 responses linearization and compensation are implemented in the user software in order to achieve full specified measurement accuracy. User software also includes nonlinear functions for dew-point and light level calculation.

The front panel is divided in two parts which may be selected by ON-LINE and OFF-LINE tab controls. ON-LINE acquisition (default page) process starts by pressing the START button. After the virtual serial port opening, the instrument's hardware initialization executes by writing appropriate start string to the port. After that, the program continues within the while loop reading ten raw data bytes from the port, processing data and displaying right values of the quantities. Finite results program sends to the waveform charts and digital indicators. Described while loop cycle will be repeated in accord with the choosen sampling time. Minimal sampling time is one second and can be adjusted as integer multiple of the minimal sampling time. On-line acquisition process may be terminated by pressing the STOP button. In this way the program leaves while structure then sending the stop character to the instrument's hardware and the port closing. CLEAR GRAPHS button serves for occasionally graphs cleaning after longer acquisition time. During on-line acquisition, the user can uses on-line help, which includes electronic user guide and technical specifications of the instrument (ON-LINE-HELP button). The mentioned while loop includes the case structure with ready-made file I/O functions.

Write to spreadsheet file starts by turning on the vertical toggle switch LOG TO FILE - recording start. Header of the file, including text control comment on the front panel, sampling period and current system date/time string, first will be saved into the file and then data field, which represents six channels. The file path and name are specified in the text control on the front panel. File writing process may be stopped by turning off the vertical toggle switch – recording stop.

The user can selects the off-line monitoring mode by clicking on OFF-LINE tab control. Then by clicking on READ FILE button, new open window offers list of recorded files. In this mode the program reads data from chosen spreadsheet file and represents the recorded waveforms in the graph, as in Fig. 4. Spreadsheet ASCII file containing the measurement data may be interpreted by any tabular programs like MS Excel, Matlab etc. This mode of the user software stops automatically at the end of file.

Fig. 4. shows the front panel at off-line mode. As can be seen there are six cursors with the cursors legend for two temperatures, humidity, pressure, light level, dew-point and administrative data reading, graph pallete with zoom tool and scale legend. In the recorded time interval the front panel at off-line mode automatically shows min, max and average values for all of six quantities. Numeric display of chosen sampling period in seconds and text display of the comment from header of the file are also available.

Described user software may be modified and upgraded easily by adding new functions for both operating modes. If some iregulars occur during the on-line acquisition like sensors disconnection the software will automaticaly abort acquisition process. Changes of the parameters as port number and sampling time will not be accepted if they made during on-line acquisition process.

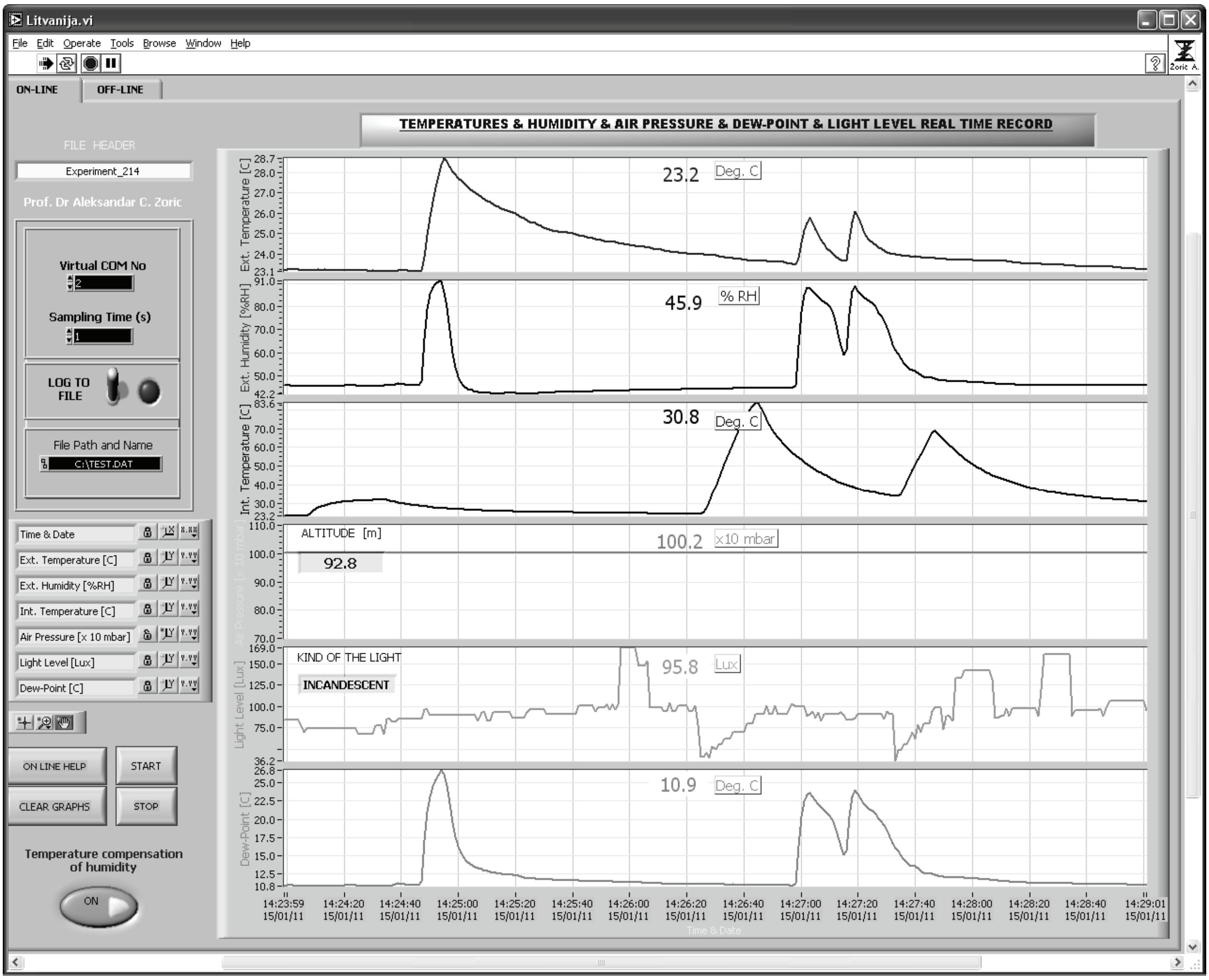

Fig. 3. On-line front panel view of the system with real time temperatures, humidity, pressure, light level and dew-point waveforms and with light type and altitude indicators

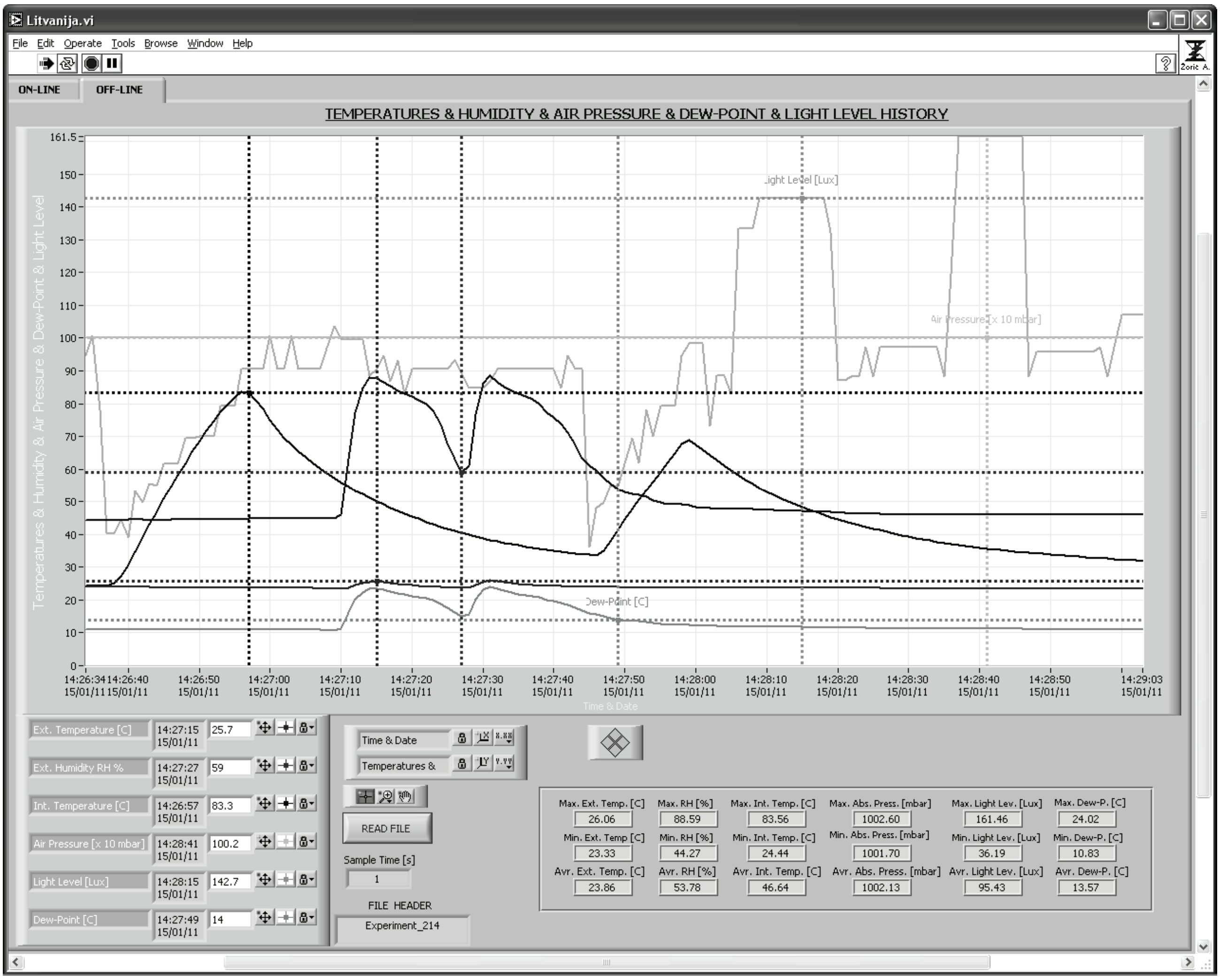

Fig. 4. Off-line front panel view of the system for recorded waveforms monitoring

Conclusions

The described PC-based multisensors data acquisition and analysis system is based on the modern virtual instrumentation concept and recently developed digital sensors.

The realized system might be widely used in many applications, where complex and relatively expensive stand-alone acquisition system developments are required.

The total cost of development, realization and system maintenance is reduced due to application of digital sensors and LabView programing tools.

The system is primarily intended to the scientific laboratory but it can be used efficiently as a part of the weather stations, smart house applications etc.

Acknowledgement

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The hardware and software solution of the virtual multisensors data acquisition and analysis system, intended for more laboratory setup is described in this paper. The system uses recently developed digital and analog integrated sensors for acquisition of temperature, relative humidity, ambient light level and atmospheric air pressure. The system also calculates and displays the pressure altitude and the kind of the light as well as depicts the dew-point waveform. Communication between the acquisition hardware and PC is established via USB port of the PC or precisely by emulating RS232 over USB. At the same time the power lines of the USB port serve as power supply lines of the acquisition hardware. Due to the precalibration of the recent sensors, expensive system calibration procedures are avoided and thus the cost of the system maintenance is reduced. The graphical user interface (GUI) is realized under LabView 7 Express integrated development enviroment. Ill. 4, bibl. 10, tabl. 2 (in English; abstracts in English and Lithuanian).

A. Žoric, D. Perišic, S. Obradovic, P. Spalevic. Virtualios multisensorinės duomenų kaupimo ir analizės sistemos projektavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 10(116). – P. 49–54.

Pateikti virtualios multisensorinės duomenų kaupimo ir analizės sistemos, skirtos laboratoriniams įtaisams, techninės ir programinės įrangos sprendimai. Sistemoje naudojami neseniai sukurti skaitmeniniai ir analoginiai integruotieji temperatūros, santykinės drėgmės, aplinkos šviesos lygio ir atmosferos oro slėgio jutikliai. Sistema taip pat skaičiuoja ir atvaizduoja aukštį virš jūros lygio ir šviesos tipą. Sąsaja tarp sistemos ir kompiuterio sudaryta per USB. Kartu USB panaudotas kaip sistemos maitinimo šaltinis. Išankstinis panaudotų jutiklių kalibravimas leidžia išvengti brangiai kainuojančio sistemos kalibravimo. Grafinė vartotojo sąsaja gauta naudojant integruotą kūrimo aplinką „LabView 7 Express“. Il. 4, bibl. 10, lent. 2 (anglų kalba; santraukos anglų ir lietuvių k.).