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Atmospheric Data Logging System

Abstract

In this paper design and implementation of a portable data logging system for atmospheric parameters measurement monitoring and analyses is presented. The system measures a variety of weather parameters, including: air temperature; relative humidity; dew point; atmospheric pressure and air contaminants. As sensing elements to measure pressure, temperature and humidity of the air it is suggested to use the integrated sensors. For air contaminant measurement a new type thick film metal oxide semiconductor gas sensor is used. This sensor displays high selectivity and sensitivity to low concentrations of various air contaminants such as combustible or solvent vapors. As measurement hardware is selected a USB multifunctional data acquisition board (DAQ), designed to work with standard desktop and laptop PCs. Additional parameters related to atmospheric air are derived by appropriate calculation in LabVIEW graphical programming environment.

Introduction

Data logging is the process of using a computer to collect data through sensors, analyze the data, save and publish the results of the collection and analysis. This process is commonly used in scientific experiments and in monitoring systems where there is the need to collect large amount of data in cases where accuracy is essential. Examples of the types of information a data logging system can collect include temperatures, sound frequencies, vibrations, times, light intensities, electrical currents, pressure and changes in states of matter.

Every data logging application can be broken down into a set of five common functional requirements – acquire, online analyses, logging, offline analysis and display (sharing, reporting) [1]. Acquiring is the process of actually measuring the physical parameters and bringing them into computer. Online analysis consists of any processing done to the data while system are acquiring. It includes alarms, data scaling, and sometimes control,

among others. Logging, or storing, the data is an obvious requirement of every data logging system. Offline analysis is everything done with the data after it has been acquired in order to extract useful information from it. The final functional block is made up display, reporting, and data sharing.

For atmospheric measurement, data loggers have been used to measure atmospheric parameters, such as temperature, pressure, humidity, wind, and solar radiation. The typical data logger is battery powered and includes a sensors, microprocessor, memory, and computer interface. The sensor measures some parameter and generates a signal indicating the measurement. Data is derived from the signal, and the microprocessor stores the data in the memory. The microprocessor may time stamp the data. Subsequently, the data is transferred from the memory to a computer through the computer interface. The computer then analyzes the data. Unfortunately, these data loggers may require too much power or may not be rugged enough for lengthy field service. The data loggers may also be too heavy and cumbersome for effective use outside laboratories. In addition, current data loggers can be complex to operate and may require too much engineering for some users.

The presented paper is related to the field of atmospheric measurement, and in particular, to a portable virtual system that receives, stores, and transfers data indicating atmospheric parameters. The developed system displays data in a number of views, which can be activated as and when required. These views can be activated both during and after data collection. Measured data is stored in database and can easily be transferred to other applications. Graphs can also be saved to disk and data from the spreadsheet can be saved in text format. The presented virtual logging system also supports IP networking so it is possible to transfer measurements from a remote site via an existing LAN, company network, or even over the Internet.

Hardware design of data logging system

The block diagram of proposed logging system for atmospheric data measurement and monitoring is shown in fig. 1. As can be seen from the figure the system consists from four sensing elements respectively for temperature, relative humidity, pressure and air contaminant measurement. Choosing appropriate sensors can often be difficult task because big differences exist between different sensors or atmospheric data measurement device types.

In this presentation in order to monitor temperature humidity and pressure of the air is

suggested to use the recently appeared new integrated sensors. These sensors have on-chip compensation, calibration, and amplifier signal conditioning that allow interface directly to any data acquisition board. Usually the integrated sensors translate the physical quantity into corresponding voltage that is directly compatible with ADC inputs of data acquisition systems (DAQ) [2, 3, 4, 5]. They are simple to use, often needing only three connections: a dc supply, ground, and signal output.

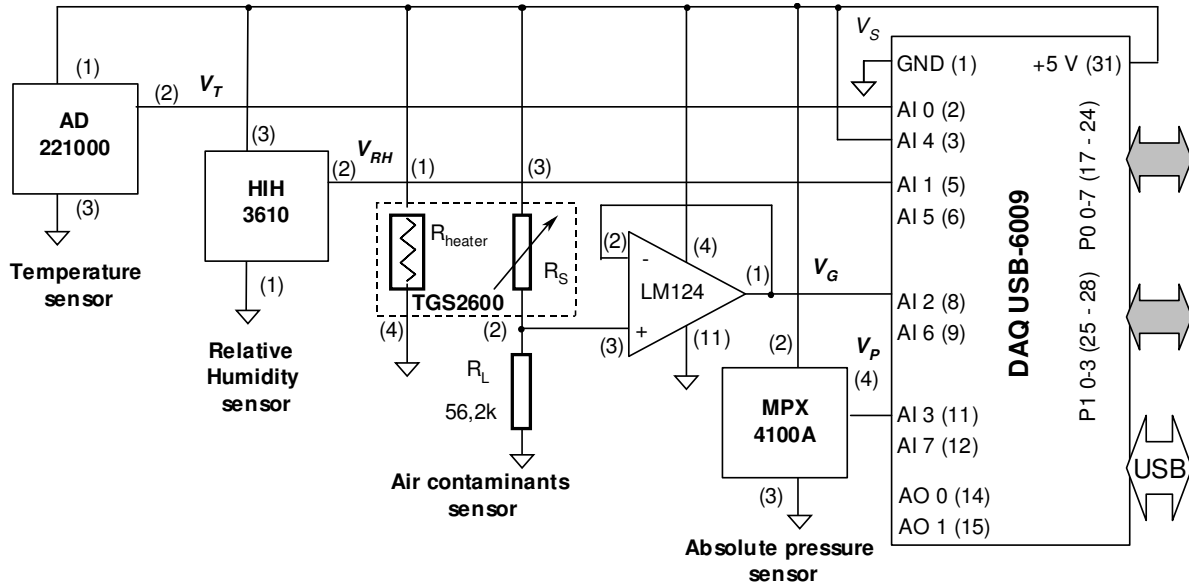


Fig. 1. Block diagram of the atmospheric data logging system.

To develop atmospheric data logging system, the following integrated sensors are chosen: AD22100 by Analog Devices for temperature measurement; HIH-3610 by Honeywell for Relative Humidity (RH) measurement and MPX4100 by Freescale for pressure measurement.

The AD22100 is a monolithic silicon temperature sensor with single-supply operation, ability to measure negative temperatures without requiring a negative power supply, and a voltage output that is ratiometric to its power supply, rather than to an absolute voltage.

The relationship between generated from AD22100 voltage V_T and ambient temperature T_A can be derived from [3] and is:

$$(1) \quad T_A = \frac{1}{0.00225 \frac{V}{^{\circ}C}} \left(\frac{5V_T}{V_S} - 1.375V \right),$$

where V_T is voltage generated from sensor and V_S is supply voltage.

The HIH-3610 sensor consists of RH laser trimmed thermoset polymer capacitive

sensing element and on-chip integrated signal conditioning. The sensing element is with multilayer construction that provides excellent resistance to application hazards such as wetting, dust, dirt, oils, and common environmental chemicals. Direct input to a data acquisition board is made possible by sensor's linear voltage output. Using the same approach as for temperature the transfer characteristic of the RH integrated sensor can be derived from [4]:

$$(2) \quad RH = \frac{1}{0.0062} \left(\frac{V_{RH}}{V_S} - 0.16 \right),$$

where V_{RH} is output voltage from the sensor.

When choosing pressure sensor it is important to consider that there are two pressure measurement types: absolute and gauge. Absolute pressure is referenced to the pressure in a vacuum, whereas gauge pressure is referenced to another known pressure level, usually the ambient atmospheric pressure. For atmospheric pressure measurement a suitable choice is integrated pressure sensors from MPX4100A series, produced by Freescale. These absolute pressure sensors are typical representative of Micro-Electro-Mechanical Systems (MEMS) and are particularly easy to use. These devices commonly employ a semiconductor diaphragm onto which a semiconductor strain gauge and temperature-compensation sensor have been grown. Appropriate signal conditioning is included in integrated circuit form, providing a dc voltage linearly proportional to pressure over a specified range.

The output voltage V_P generated from selected integrated sensor is given in [5] and the general equation used to convert output voltage to pressure is:

$$(3) \quad P = \frac{1}{0.001059} \left(\frac{V_P}{V_S} + 0.1518 \right),$$

where P is absolute pressure in kPa.

Due to mentioned benefits and capabilities of the integrated sensors the connectivity between sensing devices and acquisition hardware can be accomplished without additional signal conditioning as is shown in figure 1. As can be seen, after physical parameters have been converted into electrical signals, the signal connectivity, signal conditioning, and analog-to-digital conversion are accomplished with a plug-in data acquisition (DAQ) board. As power supply for the integrated sensors the DAQ's digital supply voltage $V_S = 5 \text{ V}$ is used. Should be noted that analog input channels are configured for reference single ended (RSE) measurements.

For detection of air contaminants most appropriate choice is TGS2600 by FIGARO [6].

The main features of the TGS2600 sensors are high selectivity to low gas concentrations, low power consumption, small size and long life. This type of tin dioxide sensor is widely used for the detection of air contaminants such as carbon monoxide, methane, hydrogen, iso-butane etc. The selected tin dioxide sensor consists of sensitive tin oxide and heating element. The heating element is used to regulate the sensor temperature, since the sensor exhibit different gas response characteristics at different temperature ranges. In the presence of gas, the metal oxide causes the gas to dissociate into charged ions or complexes, which results in the transfer of electrons. A pair of biased electrodes is imbedded into the tin dioxide to measure its conductivity change. The change in the conductivity of the sensor resulting from the interaction with the gas molecules is measured as a signal. Typically, a solid-state sensor produces a very strong signal, especially at high gas concentrations.

In the figure 1, the basic connectivity of gas sensor is shown. Circuit supply voltage V_S is applied across the sensor element, which has a resistance R_S between the sensor's two electrodes and the load resistor R_L connected in series. DC voltage is always required for the circuit voltage, and the polarity shown in fig. 1 must be maintained [6]. The sensor signal V_G is measured indirectly as a change in voltage across the R_L . The R_S is obtained from the formula:

$$(4) \quad R_S = \frac{V_S - V_G}{V_G} R_L$$

With pure air R_S is high. With the presence of detectable gases, R_S changes with the variation of gas concentration. Since V_S is a fixed voltage, by measuring the voltage on the resistor R_L , the change on R_S as well as the gas concentration can be calculated. Pins 1 and 4 are connected to the heater of the sensor, and the resistance between them is designated as R_{heater} . The working temperature is as high as 400 °C.

As the output signal of the gas sensor is large enough, the interface circuit uses only a voltage follower as a buffer between the gas sensor output and the ADC. Additionally, this approach makes the system less sensitive to external interferences.

As measurement hardware for designed virtual system for atmospheric data logging a modular data acquisition board is selected. The multifunctional DAQ boards perform a variety of tasks, including analog measurements and generation, digital measurements, and timing I/O. Additionally using high performance software drivers for modular DAQ, it is possible to quickly access functions during concurrent operation. For the measuring system reported here, the National Instruments' multifunctional DAQ USB-6009 is used.

This is a part of new generation of portable low-cost modular DAQ, controlled by computer via USB [7]. As can be seen in the figure 1 the NI USB-6009 provides connection to eight analog input (AI) channels, two analog output (AO) channels, 12 digital input/output (DIO) channels, and a 32-bit counter with a full-speed USB interface. It ships with one detachable screw terminal block for analog signals and one detachable screw terminal block for digital signals. The connection between integrated sensors, gas sensor and DAQ is shown in fig. 1.

Software consideration and development

The block diagram of software components used in presented data logging system is shown in fig. 2 in order of execution during data logging.

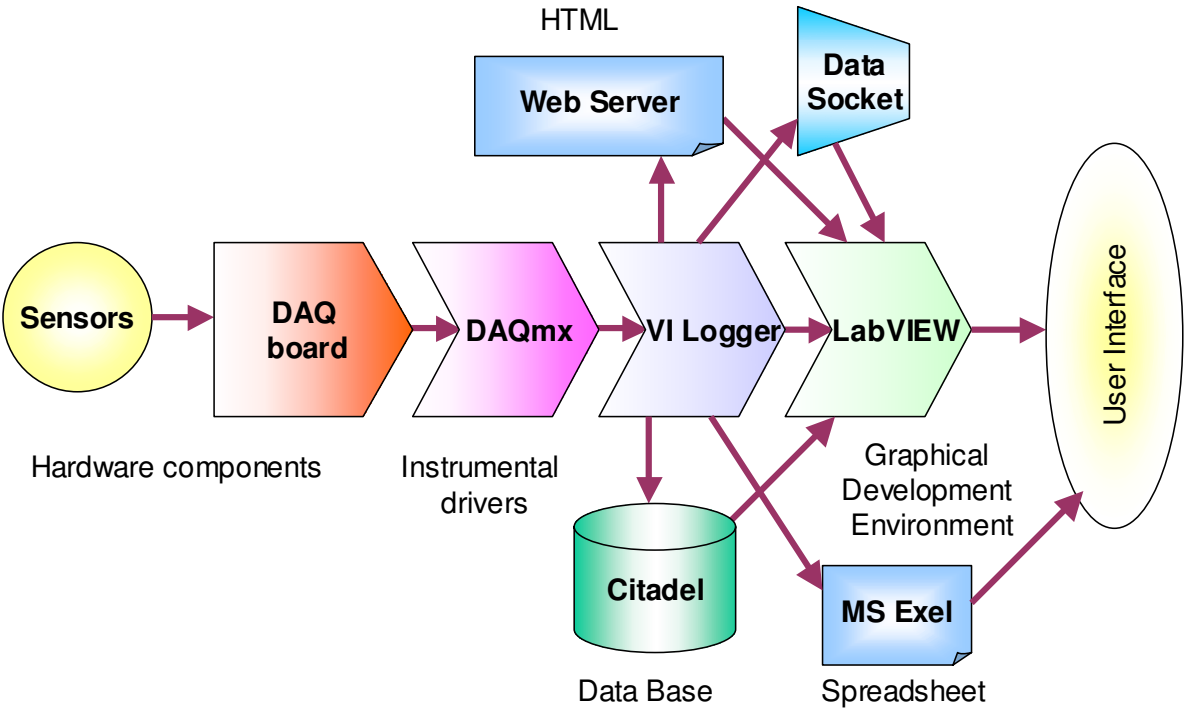


Fig. 2. Software components used by data logger system.

DAQmx driver software is an extensive library of functions and software components that can be called from application software, such as LabVIEW, LabWindows/CVI, MATLAB etc. to program measurement devices. Measurement devices include various data acquisition boards such as multifunction devices, signal conditioning modules, and switch modules. Driver software has an application programming interface (API), which is a library of components, functions, classes, attributes, and properties for creating

useful applications.

VI Logger is a flexible tool specifically designed to define and execute data logging tasks [8]. It is stand-alone, configuration-based data logging software – not a general-purpose application development environment. VI Logger gives opportunity to view real-time data in graphs, browse and manage historical data in graphs, export data to view in Web browsers and other applications. This software consists of intuitive windows and dialog boxes, to configure logging task and can be controlled by LabVIEW or use LabVIEW to analyze historical data. In order to illustrate capability of VI Logger in fig. 3 is shown dialog box for creating particular logging task. As can be seen from the figure the logging task is named “Atmospheric Data_Logging”. DAQmx task named “Atmospheric_Data” is associated with this data logging task in order to control the data acquisition board. In the middle of the dialog box are placed control components for time conditioning of data logger.

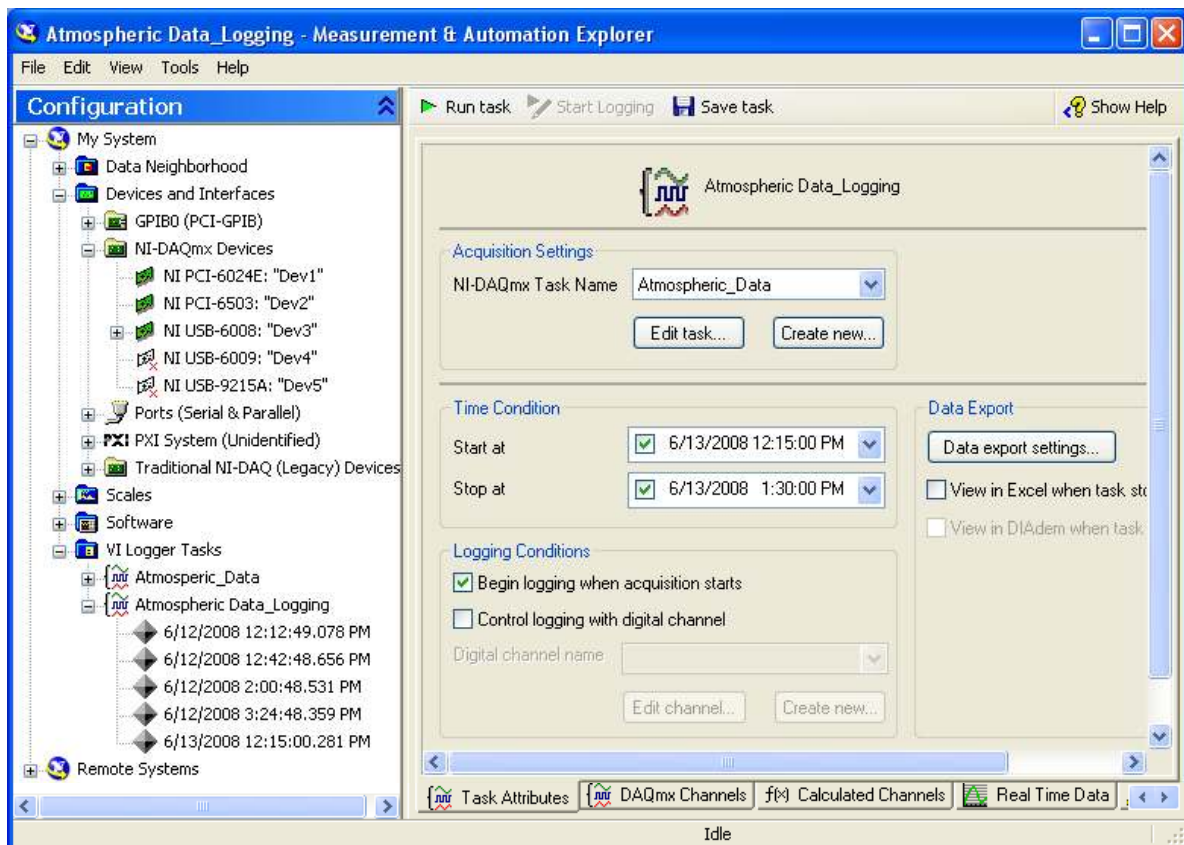


Fig. 3. Dialog box for configuration of the VI Logger.

Next software component from the fig. 2 is data base Citadel. Citadel is a common data storage mechanism and is an integral component of many software products, including LabVIEW, VI Logger, Lookout, DIAdem etc. Citadel allows these software products to

exchange industrial monitoring or test and measurement data without modifying, converting, or reprocessing the original data. This software module is optimized for real-time logging and historical data retrieval. This behavior increases application performance while saving valuable system resources, especially in large applications. Citadel does not require initial configuration, which reduces start-up and system familiarization time.

DataSocket is an Internet programming technology that simplifies data exchange between computers and applications. This technology efficiently passes data over the Internet, and responds to multiple users without the complexity of low-level programming. The technology consists of a DataSocket Server that can reside on any Windows-based computer on a network and a DataSocket API that is used to send and receive data across the network. Most of the popular development tools for measurement and automation incorporate DataSocket.

The last one of used software components is LabVIEW, an industry-leading programming and development environment for designing test, measurement, and control systems. It combines the flexibility of a programming language with built-in tools designed specifically for test, measurement, and control [9]. This development environment is based on a graphical programming language. Graphical representations are a more natural design notation for engineers and scientists than text based code and such approach to developing applications significantly reduces the development efforts. Developing large applications based on a hierarchical architecture provides encapsulation and modularity, and is therefore easier to expand and maintain. This process involves designing individual software components that performs specific functions. In a well-designed application, each component fulfills one goal or function. It is good development style in any programming language to create a good module hierarchy, and the graphical nature of LabVIEW makes the hierarchy and the code easier to understand. LabVIEW provides all necessary tools and measurement analysis functions to extract valuable information in order to obtain results from the data collected. There are more than four hundred build in LabVIEW measurement analysis, signal processing, and waveform manipulation functions. Owing to this enormous mathematical capability, in presented development is created LabVIEW components for manipulation and graphical presentation of measured data.

Manipulation of sensor's output voltages in LabVIEW environment

Ratiometric measurement

Once the sensor's outputs voltages is collected they must be manipulated appropriately in order to achieve desired atmospheric data. As can be considered from equations (1) (2) and (3) all of them can be reduces to following equation:

$$(5) \quad PF = \frac{1}{A} \left(\frac{V_{OUT}}{V_S} + B \right),$$

where PF is measured phenomena, V_{OUT} is output voltage of particular sensor, V_S is supplied voltage, and A and B are coefficients according sensor type (equalizing factors). Using this capability of sensors a more accurate measurement can be achieved applying so called ratiometric method for signal measurement. The method consists basically of continuous scanning the sensors supply voltage V_S and the sensor output voltage V_{OUT} . When these voltages are measured the software divide them according the equation (5). Because output voltage is divided on supply voltage the phenomena PF is independent of supply voltage variations. In other words this approach eliminate the errors due supply voltage uncertainties.

Temperature compensation of RH integrated sensor

Temperature compensation of RH sensor can be easy achieved using mathematical capability of LabVIEW and knowing air temperature. The compensation equation is:

$$(6) \quad RH_{comp} = \frac{RH}{1.0546 - 0.00216T_A},$$

where RH and T_A are calculated relative humidity and temperature from equations (2) and (1) respectively.

Temperature and humidity compensation of the gas sensor

As is mentioned above the detection principle of TGS sensors is based on chemical adsorption and desorption of gases on the sensor's surface. As a result, ambient temperature will affect sensitivity characteristics by changing the rate of chemical reaction. In addition, humidity causes a decrease in resistance as water vapor adsorbs on the sensor's surface. A compensation method based on capabilities of virtual instrumentation is suggested in reference [10]. The method consist of one-dimensional interpolation using a selectable tables fulfilled with data given in sensor's datasheet [6]. This method is used in presented data logging system since software accepts measured temperature and humidity and with appropriate regression function provides interpolated

value corresponding to correction coefficient.

Calculation of additional parameters

Once obtaining air temperature, relative humidity and absolute pressure a number of additional parameters related to air condition can be derived by appropriate calculations [11]. Can be mentioned: partial pressure, water vapor saturation pressure, absolute humidity, volumetric mixing ratio, mass mixing ratio, volume percent, specific humidity, enthalpy, and dew point temperature. Most popular from atmospheric data point of view is dew point.

Dew point temperature T_d is defined as the temperature to which a gas mixture at a given pressure must be cooled to achieve the saturation point of the water vapor contained in the mixture. At the saturation point the gas is holding the maximum amount of water in the gaseous state (water vapor). Any water in excess of the saturation point will condense to liquid. In addition, any surface that is below the dew point temperature will acquire condensation. When a mixture of air and water vapor is in equilibrium with liquid water or with ice, it is considered to be saturated ($RH = 100\%$). The water vapor saturation pressure p_{WS} over ice for the temperature range of -114 to 0°C is given by:

$$(7) \quad p_{WS} = (1,0007 + P3,46 \cdot 10^{-6}) 6,1121 \cdot e^{\frac{17,501 \cdot T}{240,9+T}}$$

The saturation pressure over liquid water for the temperature range of 0 to 185°C is given by:

$$(8) \quad p_{WS} = (1,0003 + P4,18 \cdot 10^{-6}) 6,1115 \cdot e^{\frac{22,452 \cdot T}{272,55+T}} .$$

Where for both expression the saturation pressure p_{WS} and total absolute pressure P is in millibars and the temperature T is in $^\circ\text{C}$.

Since there are differences between the two saturation vapor pressures and because supercooled water can exist below 0°C , the two terms dew point and frost point are differentiated. However, the general practice is to refer to either measurement as “dew point.”

The partial pressure of the water vapor p_W is given by:

$$(9) \quad p_W = RH \cdot p_{WS} .$$

For the dew points in the range of 0 to 100°C T_d in $^\circ\text{C}$ is given by:

$$(10) \quad T_d = \frac{a_0 + a_1 x + a_2 x^2 + a_3 x^3 + c p_W^{0,1964}}{1.8} - 32,$$

where $x = \ln p_W$ and if p_W is in psi, empirical coefficients are $a_0 = 100.45$; $a_1 = 33.193$;

$a_2 = 2.319$; $a_3 = 0.17074$ and $c = 1.2063$.

And for dew points below 0 °C:

$$(11) \quad T_d = \frac{b_0 + b_1x + b_2x^2}{1.8} - 32,$$

where if p_W is in psi the coefficients are $b_0 = 90.12$; $b_1 = 26.412$ and $b_2 = 0.8927$ [11].

Calculating of Atmospheric Pressure

Atmospheric pressure is the pressure at any given point in the Earth's atmosphere. In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point. Low pressure areas have less atmospheric mass above their location, whereas high pressure areas have more atmospheric mass above their location. Similarly, as elevation increases there is less overlying atmospheric mass, so that pressure decreases with increasing elevation. The equation for computing the average atmospheric pressure P_{atm} at various height regimes (below 86 km and when standard temperature lapse rate equals zero) is:

$$(12) \quad P_{atm} = P \exp\left[\frac{-g_0 M h}{288.15 R}\right],$$

where P is absolute static pressure (in pascals), h is height above sea level (in meters), R is universal gas constant: $8.31432 \times 10^3 \text{ N}\cdot\text{m} / (\text{kmol}\cdot\text{K})$, g_0 is gravitational constant: 9.80665 m/s^2 and M is molar mass of Earth's air: 28.9644 g/mol .

VI Data Logging, online and offline analysis

The front panel for online analyzes of realized atmospheric data logging system is shown in fig. 4. The first graph represents current values of temperature and dew point. In separate graphs follow relative humidity, atmospheric pressure (reduced to sea level) and air pollution respectively.

Block diagram of the created online analyzes data logging system is shown in the fig. 5. As can be seen from the figure hierarchical and modularity capability of LabVIEW are used combining with function from VI logger palette, which lead to simplicity of the presented code.

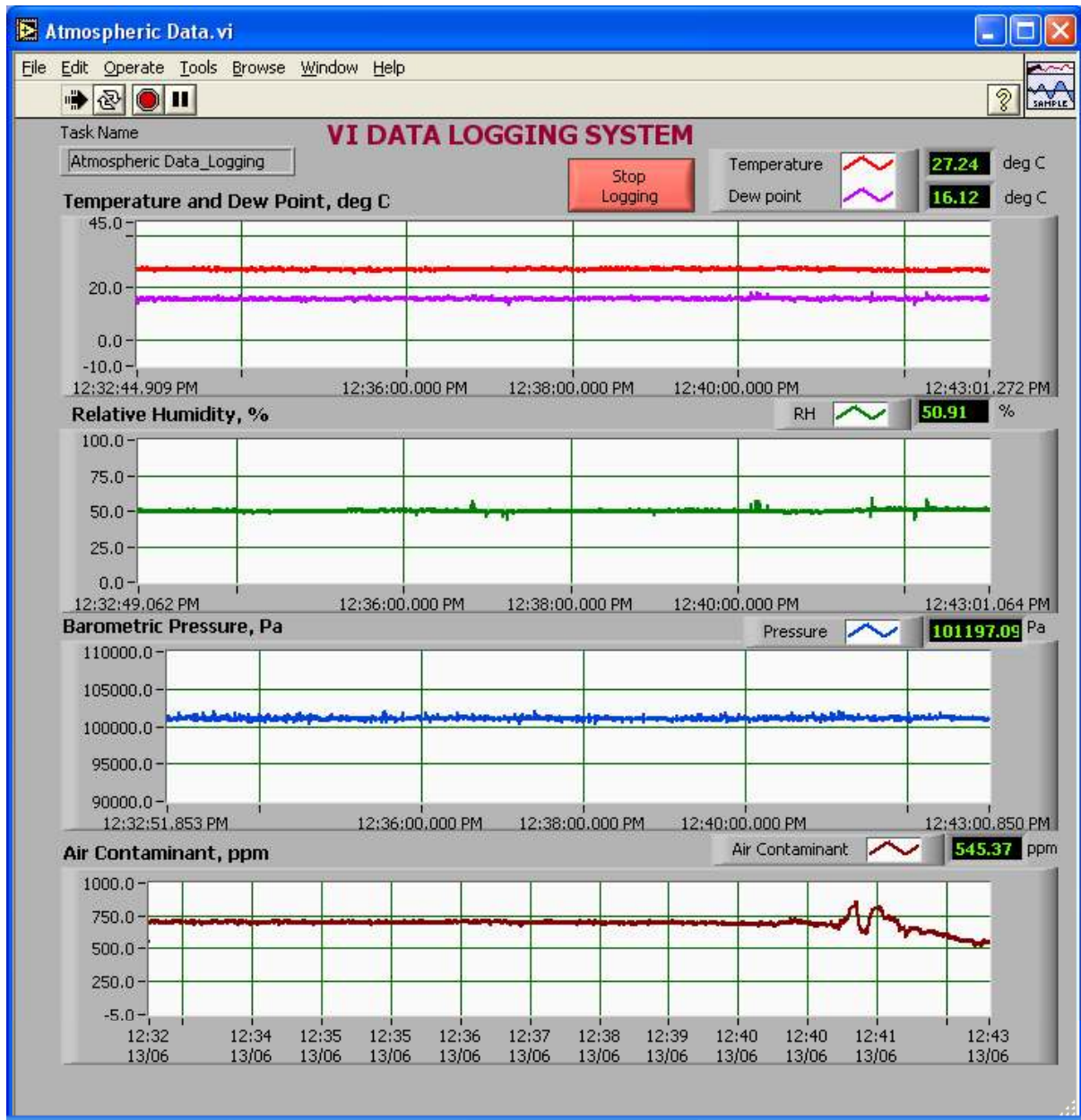


Fig. 4. Front panel for online analyzes of atmospheric data.

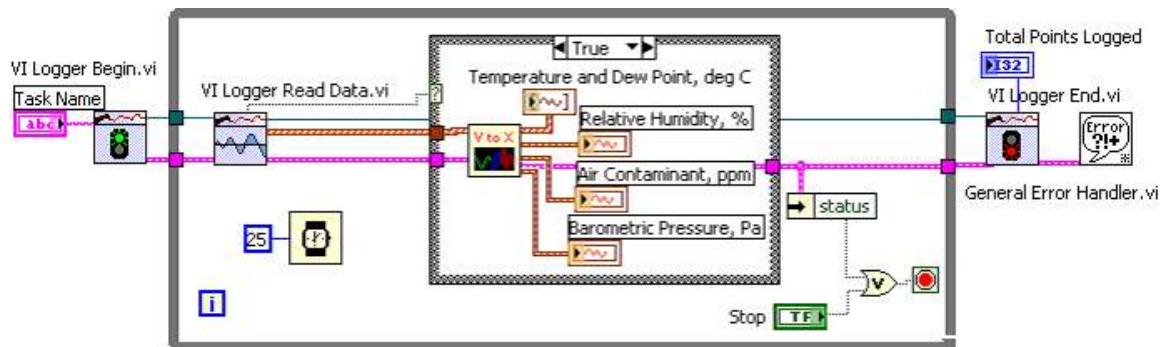


Fig. 5. Block diagram of created software for online analyzes of atmospheric data.

When the system is used in offline analyzes mode the front panel in fig. 6 is appeared. The measured parameters are similar but results are presented for full logging time and statistical information for each parameter is appended in the right part of the front panel. This statistical information includes minimal value, maximum value and arithmetic mean value for all parameters in selected time interval. Block diagram of the online analyses software is shown in the fig. 7. In similar way the LabVIEW function from VI logger palette are used combining with created function for data manipulation.

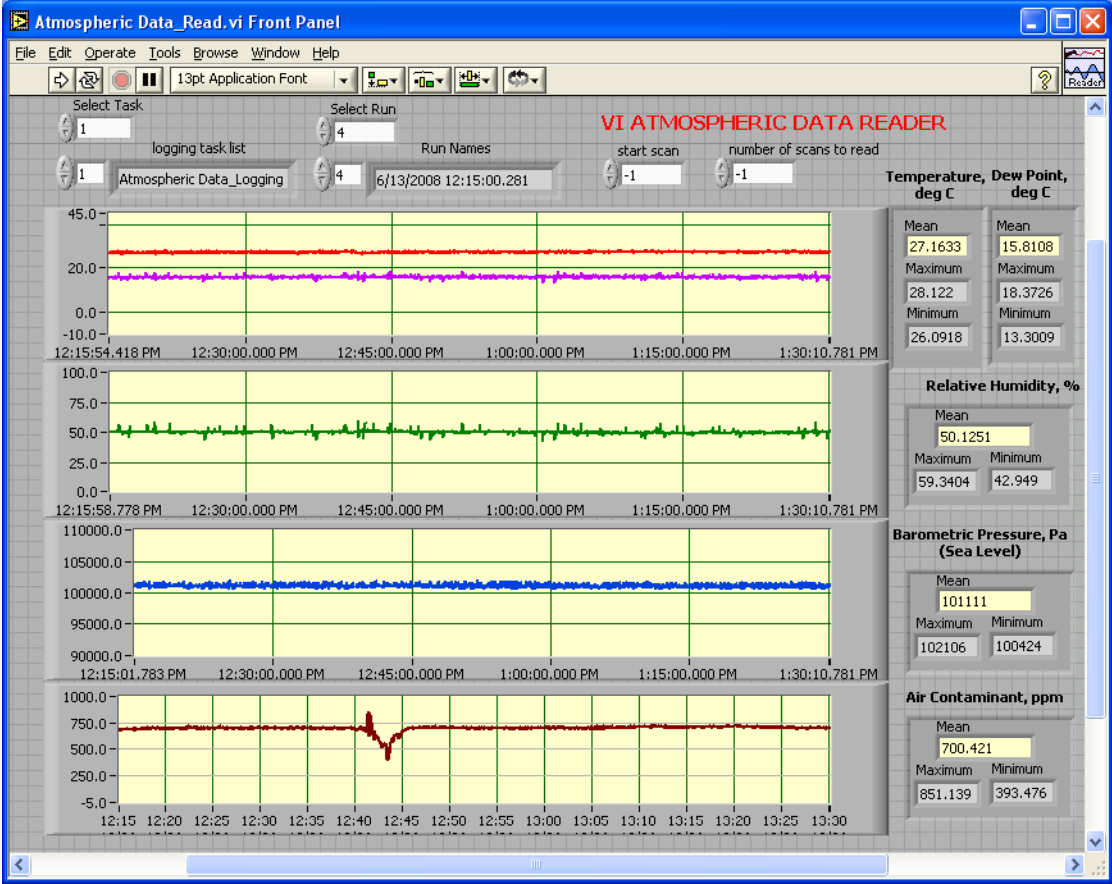


Fig. 6. Front panel for offline analyzes mode.

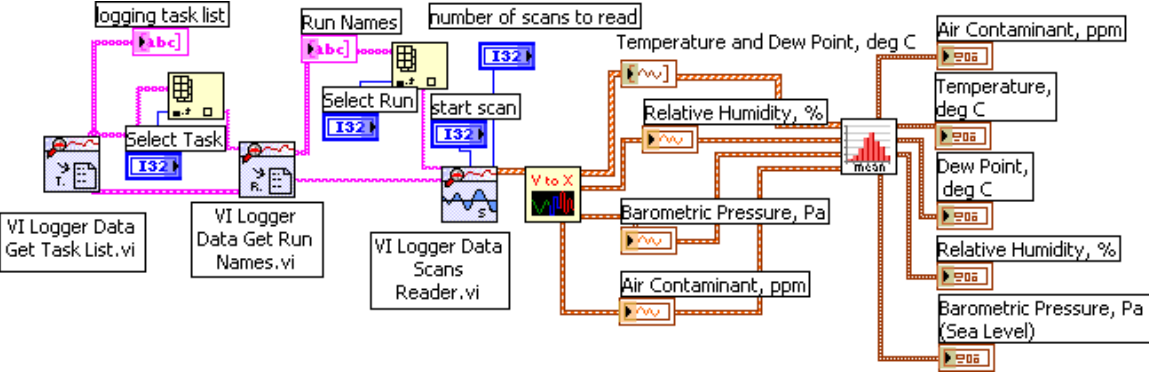


Fig. 7. Block diagram of created software for offline analyzes.

Conclusion

In the present paper, the design and development of a virtual atmospheric data logging system has been discussed. The system has been designed and built using appropriate hardware including integrated sensors, tin dioxide sensor and portable DAQ, and a number of software components (DAQmx, VI Logger, LabVIEW). This logging system is portable and affordable since it is small and inexpensive.

Methods are considered for calculating additional atmospheric parameters, temperature and humidity compensation of sensors and ratiometric measurement with sensors whose output signal is proportional to their power supply voltage.

Presented logging and monitoring system is convenient especially for those engineers and students for which the DAQ cards are available. It is well suited as for educational laboratories as for weather stations and some manufacturing sections.

The presented consideration for hardware and software design and development can be useful for engineers and designers of logging and monitoring systems of various physical quantities.

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