Towards Generic Intelligent WSN Platform for Hazardous Gases Detection

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Abstract. The focus of this work is made on standardization and unification process during the design and production of a commercially available system for gas analytical instruments industry. The implementation of Wireless Sensor Network (WSN) platform for hazardous gases detection includes the development of software which relies on the digital data exchange protocol using National Standard of Russian Federation. The goal of software is to support hardware electronics for smart gas sensitive modules and Wi-Fi wireless digital platform. This idea allows the user to work with the web application available on most mobile device (tablet PC, smart phone, etc.) using widely available free internet browsers (Mozilla Firefox, Google Chrome, etc.) without necessity of downloading any additional service software.

Keywords: Gas detection · Wi-Fi · Digital data exchange · Electrochemical gas sensor · Metal oxide gas sensor

1 Introduction

Development of the gas control equipment for industrial safety and environmental atmosphere monitoring is based on the use of gas-sensitive sensors. Since the variety of physical principles is used to convert the chemical signal into electrical, different types of gas sensors significantly vary in their electrical parameters, design and sizes [1]. Modern microelectronic technologies allow producing sensors with small size and convenient dimensions. Universal digital bus provides reliable communication of the sensors with measuring electronics. Versatility is aimed, primarily, to the convenience of the user and operational feasibility of the standard unit – gas sensing module – replacing. Currently, dozens of companies offer their products on market of gas analytical instruments [1–4]. Each of them is trying to 'fix' the consumer to its products and introduce own standard for gas-sensitive sensors. Electronics and software of gas sensitive modules are usually designed for a specific standards and data exchange protocols typical for different industries, such as chemical industry [2], air quality monitoring [3], domestic alarm systems [4], automotive production [5], etc. It is not a secret that half of the firm's profits comes from the sale of spare parts and sensors to the

B. Mandler et al. (Eds.): IoT 360° 2015, Part II, LNICST 170, pp. 250–259, 2016.
DOI: 10.1007/978-3-319-47075-7_29

previously delivered equipment. From another side in many works, attention was paid to low power consuming sensors for wireless platforms and to cloud technology enabling the communication between each sensor under harsh industrial environments [6]. There are now commercial products, for example, Wasp Mote [7] which require frequent recalibration and may result in inaccurate gas measurement, because only one sensor can be used in sensing circuit and because of neglecting environmental effects [8]. Another similar example of wireless sensor – actuator system for gas leak detection with single catalytic sensor was demonstrated in [9, 10]. Upon detection of a dangerous gas in the environment, the sensor node communicates to a remote actuator in wireless way using ZigBee/IEEE802.15.4 standard and BACnet protocol. These examples show that the multisensory platform really rare because producers and developers mainly focused on energy consumption and increasing network complexity with elements of backup for data transmission channels. From the other hand, if we talk about wireless systems for domestic monitoring, various types of implementation could be observed: the data transfer in such systems is realized by the ZigBee [11], GSM [12] or Wi-Fi [13] technologies. But mostly there is a problem of system operating with restricted accessibility [14], as well as the need to use special algorithms to collect and store large data arrays [15].

2 The Concept of WSN Platform for Hazardous Gases Detection

Taking into account all of the advantages and disadvantages describing above, we decided in our work for developing a wireless sensor network platform (WSN Platform) work without special user software and frequent recalibrations. The WSN Platform should be also easily accessible for inexperienced users. The main commercial segment for this kind of WSN Platform is private households, farms, sewage manholes, heating systems using flammable substances, etc. with inaccessibility of dangerous gas sources location. From the one hand WSN Platform should have an open and easy access interface to the user, from the other hand signal should not be extended beyond 30 m from the place of the source (to avoid admission of any unauthorized person to the signal).

Based on the presented reasons we chose Wi-Fi as a wireless data transfer standard. This standard is supported by most modern mobile devices (laptop, smart phone, etc.). For data exchange between sensors and mother board of the wireless digital platform, we chose open digital protocol according to Russian National Standard “Digital intellectual gas sensitive modules” [16]. This choice enables the application of any type of gas sensors only limiting by sensor package dimension and value of sensor power supply (voltage and current).

The hardware concept WSN Platform in first is creating a series of sensors with digital modules, having unified digital interface, communication protocol and standardized set of commands as well as setup, calibration and verification methodic. The sensors should have the ‘hot swap’ (PnP) ability as well as identification and configuration in the system after connection. The second idea of concept is have a separate transmitter as a base for digital gas sensor modules.

3 Interface and Digital Data Exchange Protocol

Figure 1 shows the structure of system with several sensors. It consists of a controlling processor (MASTER) and a number of sensors (SLAVE) with digital modules. Controlling processor sends commands and receives from the sensor the result of commands execution. Digital interface is the SPI bus. It has several advantages over the I2C or 1-wire ones. It provides hardware destination choice by the SS (Slave Select) signal and duplex synchronous exchange, which allows reliable and quick work in a system with several sensors on a single bus.

For the I2C bus or 1-wire bus work it is necessary to pre-install the unique serial number of the device on the bus, which may require changes (reprogramming) during the device (sensor) replacement. It is not considered appropriate to multiplex different digital bus types in digital interface, as this leads to a complication of procedures for incorporation in sensors and eventually decreases the reliability of the sensor system identification. Sensors with digital modules must contain a microcontroller providing data exchange with SPI-bus, managing, converting the sensor signal from the sensing element, and storage of the settings and sensor calibration data. Communication protocol must be the same for all sensors without exception. It consists of the system controlling processor request and the response of the sensor. Request consists of a start byte, command byte, data bytes and checksum. Sensor response consists of a start byte, the sensor status byte, data bytes and checksum. The composition of the commands set may differ for different types of sensors, but it must be unified. If, for example, team number 0 × 10 instructs to read voltage value of the sensor, the command for all types of sensors should be numbered 0 × 10. System controlling processor constantly asks the system for new sensors connecting, manages the connection of new sensors and receives data from the already connected sensors.

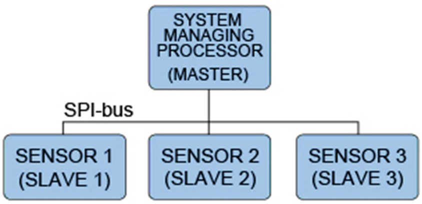

Fig. 1. The block diagram of the system working with several digital sensors.

3.1 Software and Programming for Gas Sensors Digital Modules

The digital sensor programmer is intended for programming, calibration and testing of sensors and consists of a programmer and control program for the PC. The program runs on Windows XP and Windows Vista. The programmer has 8 channels (ports) for digital sensor modules (Fig. 2). The programmer has the ability to operate as a separate sensor mounted on the selected channel, and a group of sensors located in different channels. In this case, the operation of the sensor configuration reading will still remain individual, and data write operation and calibration of the group are carried out with all installed digital sensor modules.

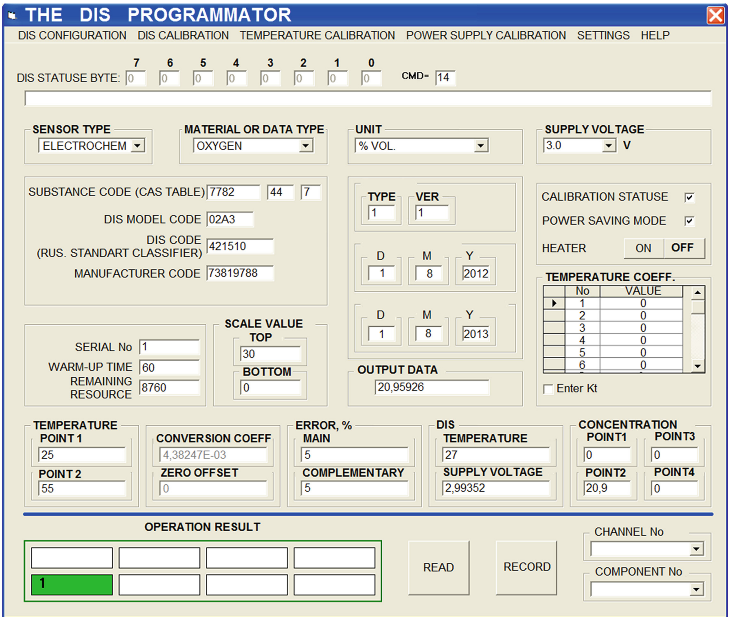

Fig. 2. The main program window contains a field for digital sensor configuration.

With the help of the digital sensor programmer could be performed the following operations: data reading from the digital sensors modules, the digital sensor modules configuration entry, working with the pre-installed table of chemical compounds CAS. Setting or status the configuration of the digital sensor modules can be saved in the database. After configuration recording the digital sensors modules can be calibrated. Sensors calibration always starts with the temperature calibration. It is important that this calibration has been performed at the very beginning, since precise data on the temperature required for proper calibration of the sensor to the measured value (component). In sensors with built-in heater the first calibration is conducted together with the heater calibration. Heater should be turned off and cooled before calibration. Absolute error of temperature measurement with one-point calibration is ±10 °C; with two-point calibration is ±3 °C in the temperature range from −40 °C to +80 °C. After the calibration of the temperature digital sensors modules can be calibrated by component (output value). Also during operation digital sensor modules constantly monitors the supply voltage. For its accurate measurement of the sensor must be calibrated to the supply voltage. Measurement error after calibration voltage is equal to 1 %.

3.2 Digital Module for Electrochemical Gas Sensor

One of the easiest in terms of technical implementation for digital modules is the oxygen gas sensor based on electrochemical sensing element O2-A3 [17] produced by Alphasense Ltd. Photo electrochemical oxygen sensor with digital module presented on

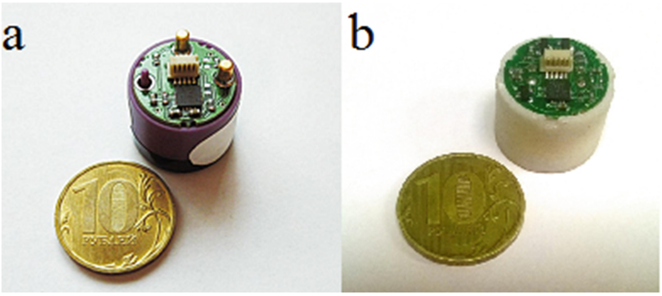

Fig. 3. (a) Photo of electrochemical oxygen sensor in 20 mm package installed on PCB of digital module; (a) Photo of CO metal oxide sensor in 20 mm ABS plastic package installed on PCB of digital module.

Fig. 3. Sensor circuit is present on Fig. 4. Electric circuit of the digital modules for electrochemical sensor is based on the Atmel microcontroller ATTINY84-20MU in QFN20 package with dimensions of 4 × 4 mm [18]. The microcontroller has a 10-bit ADC with differential inputs and internal amplifier. The inclusion of the sensor by differential scheme is convenient in terms of sensitive elements use with current output, because to produce an output by voltage, sensor output is shunted with small magnitude resistor (about 100 ohms). The microcontroller comprises a temperature sensor whose accuracy is low (±2 °C after calibration in the temperature range of 40…80 °C) but allows providing temperature correction of the electrochemical sensor response.

3.3 Digital Module for Metal Oxide Gas Sensor

More complicated example of technical implementation of digital gas sensor modules is carbon monoxide gas sensor based on semiconductor metal oxide sensing element fabrication of our past work [19]. The electric circuit of digital modules for metal oxide gas sensor and photo of semiconductor metal oxide sensor with digital module are presented on Figs. 5 and 3b respectively.

Main complication of sensor system development with semiconductor metal oxide sensor consists in relativity high temperatures necessary in sensors working conditions [17]. The heating process has two negative factors – power consumption and load to processing power of microcontroller responsible for temperature management. Power reduction could be done by pulse heating mode using, also in work [19] was investigated trade-off between sensitivity of such sensors type and power consumption during the heating. In the work [4] was shown that most energy efficient and reliable mode of system operation is at 70–80 % PWM, with maximum temperature heating up to 450 °C. Using this fact we developed electronic controller with PWM regime for semiconductor sensor heating.

Scheme of the digital module is based on the Atmel microcontroller ATTINY84-20MU in QFN20 package with dimensions of 4 × 4 mm (Figs. 3b and 5). The microcontroller has a 10-bit ADC with differential inputs and internal amplifier which using for measuring resistances of sensor's metal oxide gas sensitive layer and

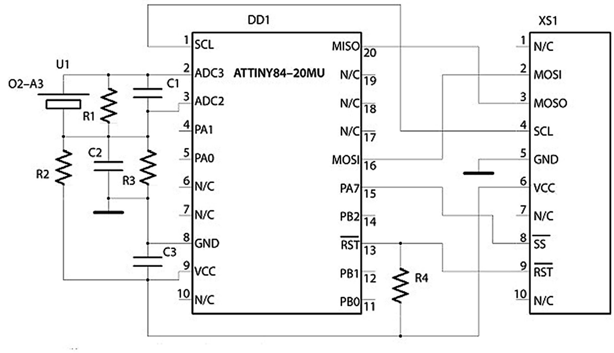

Fig. 4. Electric circuit of digital module for electrochemical O_2 sensor. GND - ground; VCC – voltage supply; RST - reset the sensor controller by low level; Trst > 10 ms; MISO, MOSI, SCL – SPI interface bus lines; N/C – not connected output.

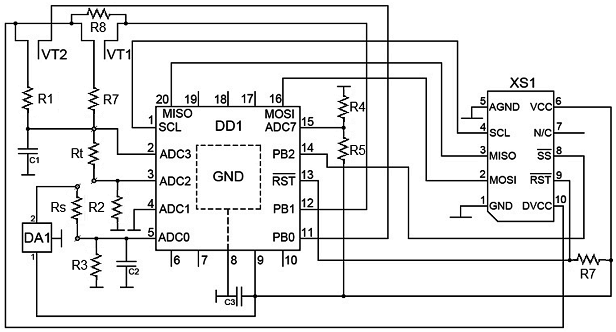

Fig. 5. Electric circuit of digital module for metal oxide CO sensor. GND - ground; VCC – voltage suplay; RST - reset the sensor controller by low level; Trst > 10 ms; MISO, MOSI, SCL – SPI interface bus lines; N/C – not connected output.

platinum heater each PWM cycle. Measurement resistance of the platinum heater plays an important role in the calibration of the metal oxide gas sensor. It is important to know in advance the temperature coefficient resistance for sensor's platinum heater by which the subsequent calculation is operating temperatures for measuring different gases (these temperatures can vary by tens and hundreds of °C for various gases and metal oxide gas sensitive layers).

4 WSN Platform for Hazardous Gases Detection

4.1 Software Implementation WSN Platform

The WSN Platform software consists of two major parts - built-in and client part. Built-in part was written in “C” programming language and uses functional

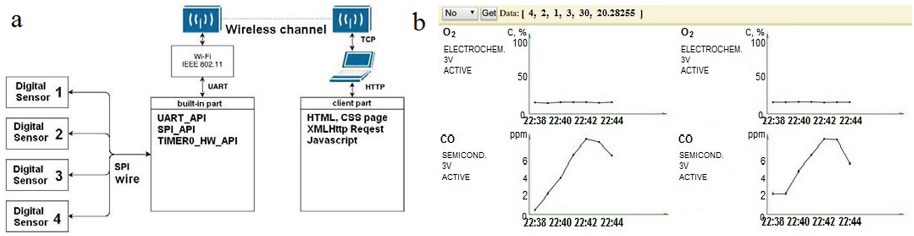

Fig. 6. (a) Software WSN Platform architecture; (b) The screen shot of the WSN Platform user software interface in internet browser during simultaneous measurement oxygen and carbon monoxide (CO) gases by two O_2 electrochemical and two CO metal oxide gas sensors.

programming techniques. The client part is implemented in object-oriented Javascript programming language. The WSN Platform software structure is shown in Fig. 6a. Client interface program runs via free internet browsers (Mozilla Firefox, Google Chrome and etc.). For lunch client-part interface program need in browser address bar need to indicate wireless network address for the WSN Platform - http://169.254.1.1. After this, network address of the WSN Platform client-side program is loaded and starts implementation. Code execution begins only after a complete download of source code of the program. The user interface of the WSN Platform is shown in Fig. 6b. The user interface has four plots showing real-time information obtained from four smart digital sensors. Near each plot small tables displays the name of measured gas, type of sensor, supplied voltage and sensor status. New points are added to the plot after each measurement and the plots shifts automatically, when the scale is full. In the upper area of the interface, there is information line displaying the last incoming JSON line and the test result of this line by a regular expression. The info line has also start key for the survey of sensors, selector that lets us choose the polling period and selector for change of alarm set up levels. An example of the JSON object: [4, 2, 1, 3, 30, 20.28255] present on Fig. 6b, where “4” is the digital sensor module number, corresponding to the position of the module on the device; “2” is the sensor type, according to the type of gas sensitive element in digital sensor module (electrochemical, catalytic, optical and etc.); “1” is the gas or another controlled parameter type; “3” is units of measurement (ppm, %, etc.); “30” is voltage supply of the digital sensor module, and the last value is the measurement result.

4.2 Hardware Implementation WSN Platform

During designing hardware for WSN Platform we focused on optimization of data transmission and neglected the minimization of power consumption. Therefore, we used the stationary power supply +12 V, although the system has an opportunity to apply the battery power supply, making the wireless digital platform independent from electrical power lines. Such approach gives possibility to use in experiments relatively powerful commercially available metal oxide sensors, consuming ~200 mW in continuous operation mode for detection of methane. However developed digital module for CO metal oxide sensors mentioned above allow to use in the future for the same purpose metal oxide or catalytic sensors with lower power consumption (about 1 mW) working in pulse heating mode describing in [20].

Strong attention was paid to the ergonomic design of the WSN platform. It was reached, for example by introducing the function of "hot swap" for digital sensors in the system. Attention was also paid not only to software implementation of this function, but also to the exclusion of mechanical errors during this operation. For these purposes, the holder was made to specifically prevent the destruction of electrical connector and to prevent a possibility of false installation of wrong type of sensor to the WSN platform. That is illustrated in Fig. 3, which shown on back side of PCB digital drivers, electrical connectors of oxygen liquid electrochemical and carbon monoxide semiconductor metal oxide sensors respectively. The holders preventing breakage of electrical connectors during "hot swap" of sensors to be installed in the WSN platform are shown in Fig. 7b.

Another ergonomic benefit realized into design is that WSN Platform does not require for work any additional software, other than widespread free Internet browsers (Mozilla Firefox, Google Chrome and etc.). However, in this approach there is a hidden conflict of price and quality of the product. The use of inexpensive 8-bit microcontroller with a small volume of RAM [18] leads to the limited capabilities of web design user software, and to the restricted number of measured point of gas concentrations and technical settings stored in memory. We plan to use more powerful microcontroller in subsequent upgrades of the WSN platform; this is justified from economic point of view, as currently the most expensive part of the device is a gas sensor, which is more expensive than microcontroller by more than one order of magnitude.

It is also possible to use the WSN platform as a standalone device. For that purpose, the WSN platform has LEDs displaying the operation status (on /off of sensors) and availability of power supply. As well, the wireless digital platform may give sound alarm using a piezoelectric sound element, depending on hazardous gases concentrations measured by digital sensors. To install the alarm levels for hazardous gases in the WSN Platform, it is possible to use internet browsers or using already present in memory default values for dangerous gas concentrations according to the maximum permissible concentration of hazardous gases substances in the working area by Russian State standard [21].

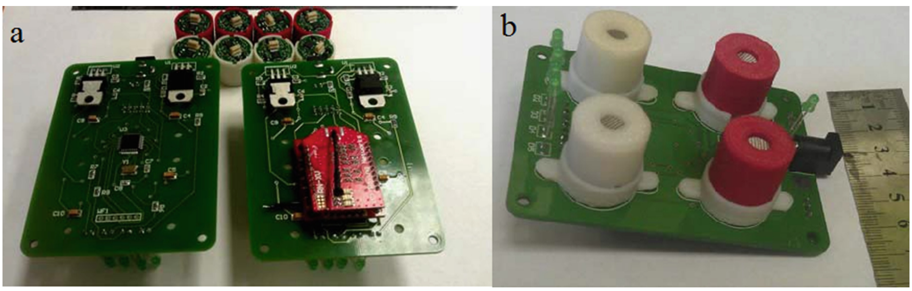

Fig. 7. (a) The bottom view of PCB of the WSN platform. The left PCB is without Wi-Fi transmitter and the right is with attached Wi-Fi transmitter; (b) The top view of WSN Platform with digital sensor modules. The attached holder preventing break of electrical connectors during "hot swap" (PnP) of digital sensors modules.

5 Conclusions

The wireless WSN Platform for hazardous gases detection with possibilities to work with up to four digital gas sensors modules was designed. The WSN Platform uses Wi-Fi standard for data transmission. Advantages of the WSN Platform are the following: opportunities to use any type of gas sensor with power consumption up to 200 mW; possibility of "hot swap" of sensors during work; standardization for 20 mm diameter typical of commercial electrochemical, catalytic and optical sensors; open digital standards for digital data exchange protocol giving chance to easily update the WSN Platform and create customer's own digital sensors. The WSN Platform does not require for visualization the transmitted data any additional software except widely available free internet browsers (Mozilla Firefox, Google Chrome and etc.).

Acknowledgments. This work was supported by grant of the Russian Federation President for young scientists №. 14.Y30.15.7910-MK from 16.02.2015.

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