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An Automatic Data Acquisition System for Optical Characterization of PEDOT:PSS-Based Gas Sensor

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Abstract. A measurement system that consists of a pair of laser diode and photodiode coupled with an automatic data acquisition system based on microcontroller of AVR ATMega16 (hereafter to be called DAQ MA-16) has been developed for measuring optical response of polymer-based gas sensor. In this case, the optical response was represented by the voltage output of the photodiode. The polymer-based gas sensor was a thin film of polymer of Poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) or PEDOT:PSS deposited on a glass substrate. For measurement, the sensor was placed in the chamber, and then the gas ammonia with a fix flow rate was flowed into the chamber. The opposite part of the chamber was installed a pump to throw the gas. The National Instrument Data Acquisition (NI DAQ) BNC-2110 has been used to calibrate the DAQ MA-16 system. From the calibration, it can be estimated that the accuracy of DAQ MA-16 is about 99.4%.

Keywords: PEDOT:PSS, data acquisition system, gas sensor, ammonia, optical response.
PACS: 82.35.Cd, 07.07.Df, 07.05.Hd

INTRODUCTION

Basically, a data acquisition (DAQ) system is a combination of software and hardware that lets us to measure or control physical characteristics of many applications. A typical DAQ system consists of sensors and transducers, signal conditioning hardware and software, and a computer running data acquisition software. When the sensors or transducers sense physical variables the output of analog electrical signals are usually very low and contains noises. Therefore, they must be conditioned to obtain the best output. For this purpose, the signals must be filtered, amplified and converted to digital signal. A linearization is also applied so that the output is proportional to the input.

A low-cost DAQ has been developed by employing microcontroller for special purpose of application. For example, a microcontroller-based current electrometer built from LOG112 and C8051F006 system-on-a-chip has been successfully developed for measuring current flowing through a MOS (metal–oxide–semiconductor) device [1-3]. Another microcontroller-based DAQ has been also developed for measuring solid content of heave rubber latex based on microwave system [4]. Furthermore, the low-cost microcontroller-based DAQ was also effectively applied in quadcopter configuration, amperometric biosensor, and design of wireless water-saving irrigation controller [5-7].

Recently, the development of gas sensors based on conductive polymers is very attractive research because of room temperature operation and easy in fabrication. Visible optical sensing of ammonia based on polyaniline film has been reported [8-9]. On the other hand, the conducting polymer of poly (3,4-ethylenedioxythiophene) doped by poly (4-styrene-sulfonate) or PEDOT:PSS has been investigated for many applications in the last decade [10-12].

Since the electrical response of ammonia gas sensor based on PEDOT:PSS has been investigated under imprinting method [13], in the present study we continue to investigate its optical response based on its transmittance by developing a low-cost ATmega16 microcontroller-based data acquisition system of DAQ MA-16. For measurement the optical response, the sensor was placed in the chamber, and then the gas ammonia with a certain flow rate was flowed into the chamber. To ensure the reliability of the DAQ MA-16, the National Instrument Data Acquisition (NI-DAQ) of BNC-2110 series has been used for calibrator.

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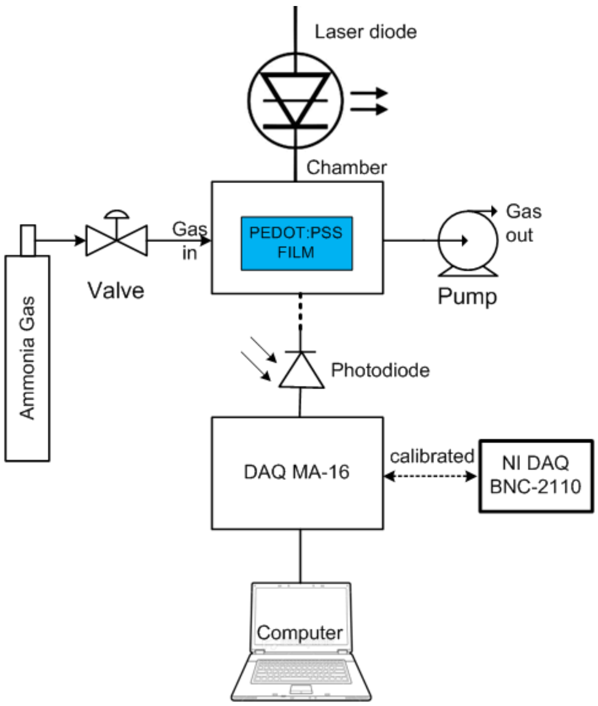
METHOD

Hardware and Software of DAQ MA-16

Block diagrams of the optical response measurement system and the microcontroller-based data acquisition system of DAQ MA-16 is depicted in Figure 1. It consists of a pair of laser diode and photodiode, transparent chamber, and microcontroller-based data acquisition system.



(b)

FIGURE 1. Block diagrams of the optical measurement system.

The red laser diode with 630-680 nm of wavelength and maximum power less than 5 mW was used as a monochromatic and coherent light source. Upon illuminating the gas sensor in the chamber by using the laser diode, a part of the light will be transmitted so that can be detected its pair of photodiode. In this case, the optical response of the sensor was represented by the voltage output of the photodiode.

The ATmega16 microcontroller has four ports, namely Port A, Port B, Port C and Port D as shown in the block diagram (Figure 2). Meanwhile, the module of AVR ATMega16 fabricated by Creative Vision version 2.0 as shown in Figure 3 has been employed in developing the DAQ MA-16. After being optimized, the photodiode was coupled by using a resistor of 20 kΩ in series. On the other hand, the ATmega16 AVR microcontroller converts the analog voltage from the photodiode output to digital one followed by sending serially to the computer via the Universal Serial Bus (USB).

From the microcontroller of ATMega16, the Pin of PA.0 and PA.1 were used as ADC input of the gas sensor. In this case, the pin of PA.0 was used for optical measurements, while the pin of PA.1 was used for electrical measurements. The pins of PD.1/TXD and PD.0/RXD serve as a serial communication between the microcontroller and the computer.

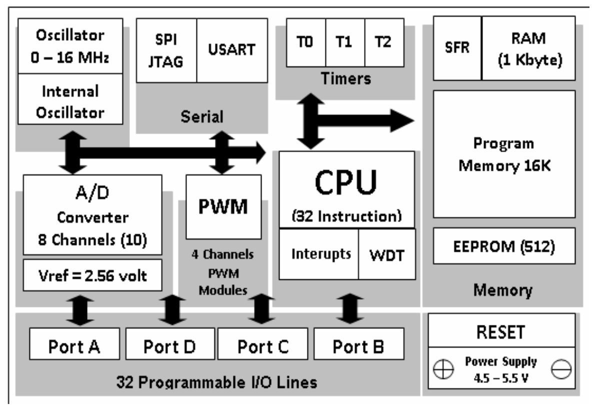


FIGURE 2. Block diagram of ATMega16 microcontroller.

Since the data acquisition system is applied to perform measurements in a real time, the measurement data may be automatically stored in a computer in the format of text (.txt).

Some features of the AVR ATmega16 microcontroller are as follows [14-16]:

1. RISC architecture with throughput to reach 16 MIPS (Microprocessor without Interlocked Pipeline Stages) the frequency 16 Mhz.
2. Has a capacity of 16 Kbyte Flash memory, 512 Byte EEPROM (Electrically Erasable Programmable Read-Only Memory), and 1 Kbyte SRAM (Static Random Access Memory).
3. 32 Channels I/O, that is Port A, Port B, Port C, and Port D.
4. CPU (Central Processing Unit) consisting of 32 registers.
5. User internal and external interrupts.
6. SPI (Serial Peripheral Interface) system interface and USART (Universal Synchronous Asynchronous serial Receiver and Transmitter) as serial communication.
7. Peripheral features:
   - Two 8-bit Timers/Counters with Separate Prescalers and Compare Modes.
   - One 16-bit Timers/Counter with Separate Prescaler, Compare Mode, and Capture mode.

- Real Time Counter with Separate Oscillator.
- Four PWM (Pulse Widht Modulation) Channels and analog comparator interface.
- 8-channel, 10-bit ADC.

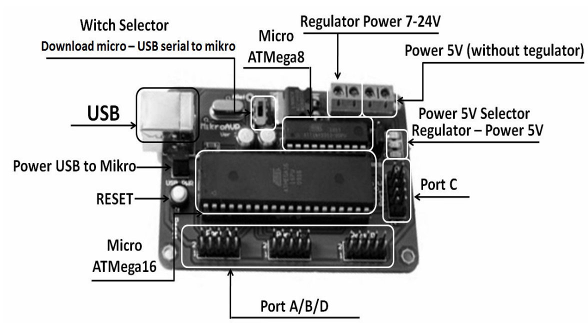


FIGURE 3. Photograph of the minimum system of "Creative Vision" version 2.0 of microcontroller used in the DAQ-MA16.

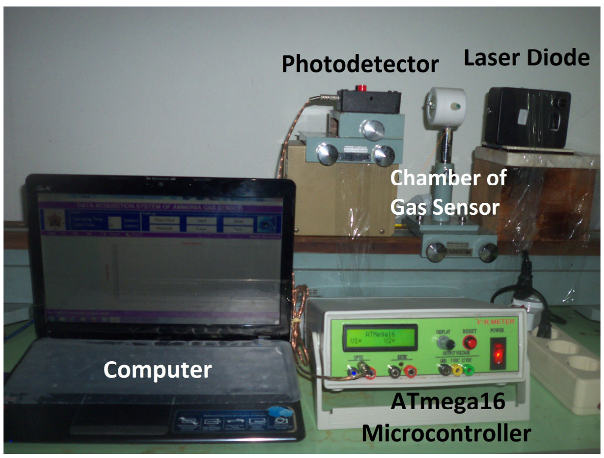


FIGURE 4. Photograph of the automatic measurement system (DAQ MA-16) for measuring optical response of polymer-based gas sensor.

Polymer Based Gas Sensor

The polymer based gas sensors were thin films of PEDOT:PSS deposited on cleaned glass substrates using spin coating system with speed of 1000 rpm for 5 minutes. After spinning the thin films of PEDOT:PSS were dried on a hotplate at 80 °C for 10 minutes, followed by installing in the chamber. The PEDOT:PSS based gas sensor (hereafter to be called sensor) is very simple because of no other treatment and electrode.

Calibration and Measurement

Before being applied for measurement of optical characteristic of ammonia gas sensor, the DAQ MA-16 was tested to measure the voltage of batteries of AA size. The output of the DAQ MA-16 was calibrated by comparing with output of NI DAQ BNC-2110. As shown in Figure 4, the pair of laser diode and photodiode (detector) was mounted opposite each other at a fixed distance of 10 cm. The laser diode used in this study was a diode laser (laser pointer) with a wavelength range of 630-680 nm. The intensities of laser diode were varied by changing the resistance connected in series to the diode laser.

Sensor response was measured by flowing ammonia gas into the chamber at a certain flow rate (on/off). The measured data could be displayed on the LCD screen of 16x2 type and serially sent to the computer.

RESULTS AND DISCUSSION

Before being applied for measurement of optical characteristic of sensor, the DAQ MA-16 was tested to measure the voltage of batteries of AA size. The output of the DAQ MA-16 was calibrated and compared to the output of NI DAQ BNC-2110. As shown in Figure 4, the pair of laser diode and photodiode detector was mounted opposite each other at a fixed distance of 10 cm. The laser diode used in this study was a diode laser (laser pointer) with a wavelength range of 630-680 nm.

Figure 5 shows voltage measurement of new batteries by using DAQ MA-16 and standard instrument of NI DAQ BNC-2110 coupled with Lab View 8.6. In this calibration step, alkaline batteries were chosen as object under test of voltage because of its good stability. The voltage of one battery measured by using DAQ MA-16 was 1.60 ± 0.04 V, while using NI DAQ BNC-2110 was 1.63 V. The voltages of two and three batteries were obtained to be 3.06 ± 0.04 V and 4.68 ± 0.04 V, respectively when measuring by using DAQ MA-16. On the other hand, the voltages of two and three batteries were obtained to be 3.08 V and 4.7 V, respectively when measuring by using NI DAQ BNC-2110. From these measurements, it can be estimated that the accuracy of DAQ MA-16 is about 99.4%.

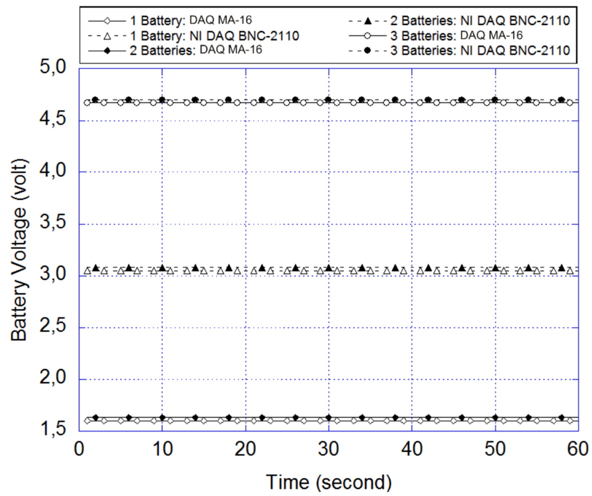


FIGURE 5. Comparison of voltage measurement by using DAQ MA-16 and standard instrument of NI DAQ BNC-2110 for calibration.

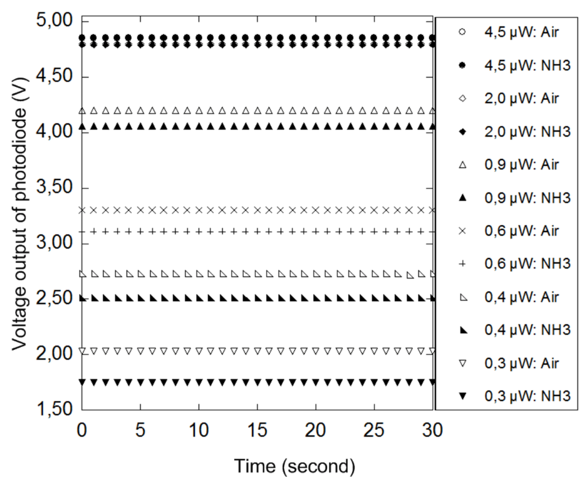


FIGURE 6. Voltage output of photodiode for interval of time as a representative of sensor response to variations in the intensity of the laser diode using the DAQ MA-16, both under exposed with air ambient or ammonia.

After calibration by using NI DAQ BNC-2110, the optical performance of DAQ MA-16 was evaluated by varying intensity of laser diode. In this case, laser diode intensities were varied by varying resistances connected in series, i.e. 300 Ω, 500 Ω, 800 Ω, 1 KΩ, 1.2 KΩ and 1.5 KΩ, respectively. These resistances were correspondingly with intensities of the laser diode i.e. 300Ω - 1.5 KΩ at 4.5 μW, 2.0 μW, 0.9 μW, 0.6 μW, 0.4 μW and 0.3 μW, respectively. As shown in Figure 6, the photodiode response (in volt) is stable for an interval of time both under exposure of air or ammonia gas for all various intensity of laser diode. For each intensity variation, there is shift to lower voltage output of photodiode after exposure of ammonia gas.

The photodiode exhibits a linear span intensity of the laser diode is less than or equal to 0.8 μW (Figure 7). The span-end nonlinearity or saturation, on the other hand, exhibits for intensity of the laser diode is more than 0.8 μW. The linear span is depicted as inset of Figure 7. Therefore, the range of measurement should be in linear span, i.e. 0-0.8 μW (power of the laser diode) with the sensitivity of about 4.5 V/μW.

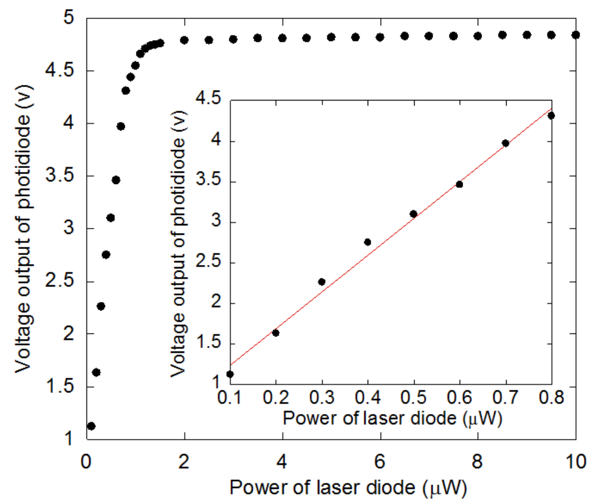


FIGURE 7. Voltage output of photodiode that exhibits a linear span and a span-end nonlinearity or saturation measured by using DAQ MA-16. Inset: linear span of photodiode.

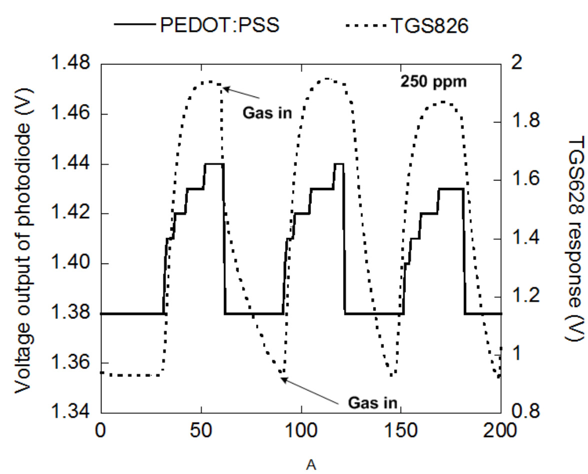


FIGURE 8. Response profile of PEDOT:PSS based gas sensor (optically) and TGS628 (electrically) to 250 ppm ammonia gas measured by using the DAQ MA-16.

After completing calibration of DAQ MA-16, the response of sensors was measured as voltage output of photodiode of DAQ MA-16 system under exposure (on/off) of 250 ppm ammonia gas. For comparison, a commercial gas sensor of TGS826 was installed parallel to the sensor. The response of TGS628 was measured by using DAQ MA-16 electrically. The response profile of these measurements is shown in Figure 8. As shown in Figure 8, by using DAQ MA-16 the sensitivity of sensor (optically) is much lower compared to that of TGS628 (electrically). Oppositely, the PEDOT:PSS based gas sensor shows much lower in recovery time to that of TGS628.

CONCLUSIONS

An automatic data acquisition system (DAQ MA-16) for optical characteristic of sensor has been developed and calibrated using NI DAQ BNC-2110. By using DAQ MA-16, the visible light source is a laser diode, while the sensor response is represented by the voltage output of photodiode. The photodiode exhibits a linear span intensity of the laser diode is less than or equal to 0.8 μW. The span-end nonlinearity or saturation for intensity of the laser diode is more than 0.8 μW. As an automatic data acquisition system, the DAQ MA-16 can be used to measure response of sensor optically and electrically.

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