Proceedings of International Conference on Man-Machine Systems 2006
September 15-16 2006, Langkawi, Malaysia

Automated Odour Measurement in Electronic Nose System Using Microcontroller

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Abstract

This paper presents an automated odour measurement process using AT89C55WD Microcontroller for the electronic nose (e-nose) system. An e-nose system has been developed to detect various hazardous Volatile Organic Compounds (VOCs); Acetone, Benzene, Chloroform, Ethanol and Methanol, which requires environmental monitoring. The complete e-nose system for the VOCs recognition consists of a lipid-coated quartz crystal sensor array, an electronic hardware interface circuitry based on a Xilinx IC and an AT89C55WD microcontroller, odour handling delivery system (i.e. flow cell, teflon tubing, pump and valves) and a neural network system. The odour measurement for the e-nose system consists of baseline measurement and vapour measurement. The AT89C55WD Microcontroller was used to control the pump and valve in order to enable the automated odour measurement process.

Keywords

AT89C55WD Microcontroller, Volatile Organic Compounds (VOCs), Electronic nose (E-nose), Pump and Valves.

1. Introduction

Over the past few years, there has been growing interest in the use of e-nose in environmental monitoring because e-nose technology provides cost-effective alternatives for accurate, reliable and speedy identification of the environmental pollutants [1]. An e-nose is an instrument that combines gas sensor arrays and pattern recognition system for the detection, identification, or quantification of volatile compounds [2]. As such, an e-nose instrument comprised of hardware components to collect and transport odours to the sensor array and electronic circuitry to digitize and store the sensor responses for signal processing [3].

2. Approach and Method

The proposed electronic nose system consists of several components. Figure 1 depicts a schematic diagram of the e-nose system setup. Five quartz crystals arranged in a flow cell were used as sensors while one quartz crystal was used as a reference. The five quartz crystals were coated with polyvinyl chloride (PVC) blended lipid as the sensing membrane. The referenced sensor was not coated with any lipid sensing membrane and hence, its frequency reading was 10MHz.

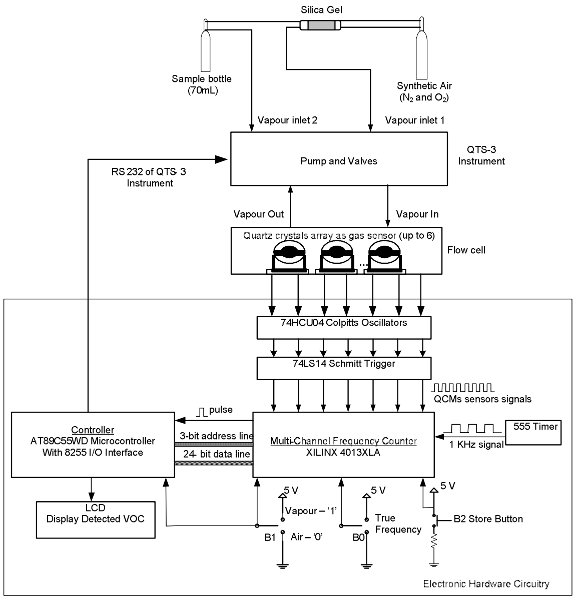

Figure 1- Schematic Diagram Of E-Nose System Set-Up

The flow cell has two openings for vapour inlet and outlet. Commercial synthetic air consisting of 80% N_2 and 20% O_2 from a gas cylinder was used to establish a baseline response. It was also used as a carrier for the tested vapours and for 'sensor cleaning' purposes. Volatile organic liquids ranging from 0.2μL to 10μL were injected into a sample bottle (70mL) using a micropipette. Silica gel, which was filled in a cylinder tube, was used as a drying agent for the synthetic air. The pump (KNF Flodos, Innovative Technology) and valves (BIO-CHEM, Inc.) which reside in the QTS-3 instrument (Quartz Technology Ltd, UK), were used for the automated odour measurement process. Teflon tubing was used to transport the vapours and the synthetic air from the sample bottle or gas cylinder into the flow cell. An electronic hardware circuitry was used for the analog to digital data conversion, data acquisition and pattern recognition process of the sensors input data. The development of a complete e-nose system set-up and the experimental procedures has been mentioned elsewhere [4].

A sample flow system was employed in this experimental setup. In this sample flow system, the sensors are placed within the vapour flow, which allows for rapid exchange of vapour and hence, many samples can be measured within a short time. The sample flow system is the most convenient odour handling and delivery system since it is easy to handle and the measurement cycle is short [3]. The vapour flow rate was at 230mL/min.

A semi-automated measurement for the e-nose system was used in this experimental setup in which the test vapour was manually injected into the sample bottle [5]. Typically, the odour sensor system experiment consists of two measurements -- the baseline measurement and vapour measurement. For the baseline measurement, the sensors inside the flow cell are exposed with the synthetic air whereas for the vapour measurement, the sensors are exposed with the VOCs to be detected. The AT89C55WD Microcontroller was used to control the pump and valves in order to enable the automated process of the vapour and baseline measurements.

The baseline measurement was done prior to the vapour measurement, in order to calibrate the sensors' reading and use them as the current reference values for the sensor-drift effect compensation [6, 7]. Hence, the baseline measurement was conducted at every level of the vapour concentration measurement. The automatic cycles of the baseline measurement are as follows. Firstly, the valve is switched open and the pump is turned on. The cell is then supplied with the synthetic air for 18s. True frequencies of the QCM sensors are measured and the baseline frequency shifts of the QCM sensors are calculated and produced by the frequency counter. Once it reaches a steady state level, the values are saved in the Xilinx IC. The baseline frequency-shift values are equivalent to the frequency-shift values of the coated sensors with the synthetic air exposure.

After completion of the baseline measurement process, vapour measurement was then conducted. The test vapour was first injected into a sample bottle using a micropipette. During vapour measurement, the sensors were exposed to the test vapours, followed by the cleaning process. The automatic measurement procedures of the vapour measurement start by switching open the valve, turning on the pump and activating the routing valve for supply of test vapour. Then, the sensors inside the flow cell are exposed with the test vapour. True frequencies of the QCM sensors are measured and the vapour frequency shifts of the QCM sensors are calculated and produced by the frequency counter. Finally, the routing valve is deactivated, and the cell is purged with the synthetic air for cleaning purposes.

The vapour frequency shifts of the QCM sensors were measured for 18s during supply of test vapour to the flow cell. The cleaning process time was set for a fixed duration of 126s where 62% (78s) of the setting time was used to clean the sensors in the flow cell and 38% (48s) of the setting time was used to clean the sample bottle and the Teflon tubing. The sensors' cleaning process time should not be less than the sampling time [8].

3. Main Algorithm of E-nose Design

An AT8955WD microcontroller was programmed using C language in the Keil Software to do 4 functions as listed below:

i. Control the pump and valves for the automated vapour and baseline measurements.

ii. Acquire the QCM frequency data from the frequency counter (Xilinx IC) once a pulse signal is received at every 1s.

iii. Process the acquired data using the embedded optimised structure of the ANN.

iv. Display the current measurement on LCD either baseline measurement or vapour measurement accordingly.

Detailed explanation on the whole process of this AT89C55WD Microcontroller can be obtained elsewhere [9]. This paper only focuses on the automated process of the vapour and the baseline measurements and also the display process during these measurements.

3.1 Main Algorithm of Odour Sensor System

The flow sequence of the main algorithm for the odour measurement process is shown in the flowchart of Figure 2.

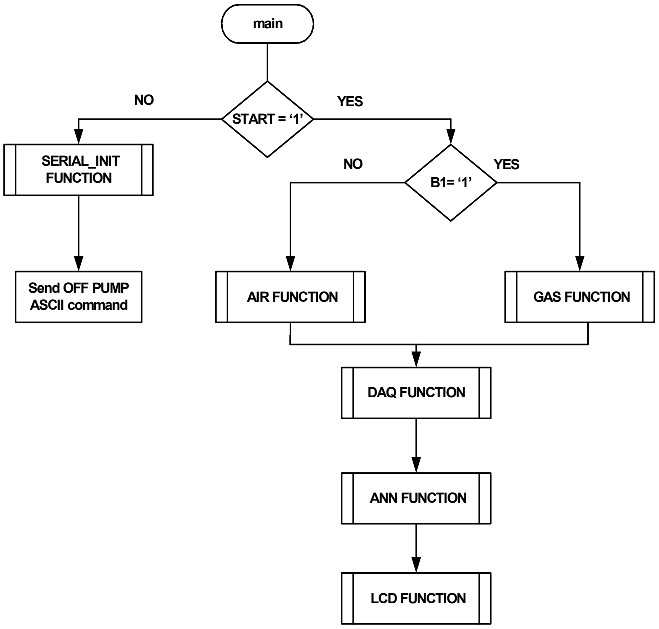

Figure 2: Main Algorithm for Odour Measurement Process

The logic input signal from the START-pin determines the condition of the e-nose odour delivery system. The source of the microcontroller START-pin signal comes from an external switch. If the START-pin signal is logic LOW, a series of ASCII commands will be sent to the pump in the QTS-3 instrument to turn off the pump. Whereas, if the START-pin signal is logic HIGH, it will go to the next conditional stage where the input signal from B1-pin determines whether the baseline or the vapour measurement will be conducted. If the input signal from B1 is logic HIGH, the vapour measurement will be conducted by calling the Gas Function subroutine. If the input signal of B1 is logic LOW, the baseline measurement will be conducted by calling the Air Function subroutine. Both of the gas and air function subroutines will call the same function subroutines for the next operation and they are the data acquisition function (DAQ Function), the pattern recognition function (ANN Function) and lastly the display function (LCD Function).

3.2 Gas Function Subroutine

Figure 3 depicts the Gas function flowchart.

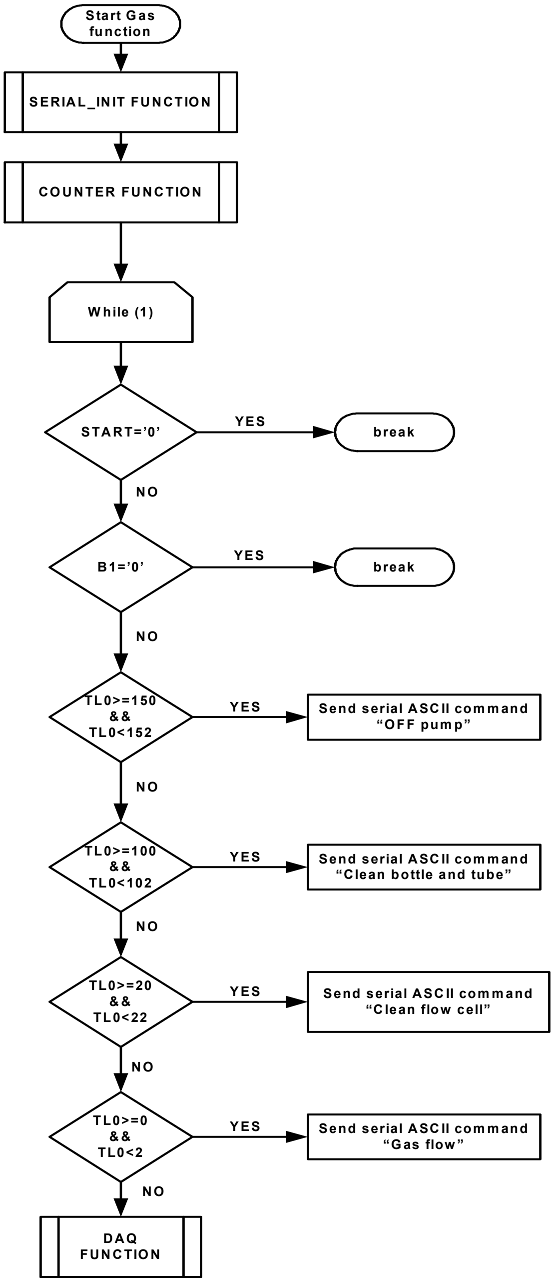

Figure 3- Gas function flowchart

During execution of the gas function subroutine, the serial and the counter functions are called and activated. The serial function is used to initialise the RS232 serial port to operate at 9600 baud rate. This will enable the ASCII commands to be sent serially through RS232 link to the pump and valves, which reside in the QTS-3 instrument. The counter function is used to activate the internal Counter 0 of the AT89C55WD microcontroller. The internal Counter 0 acts as an event counter, which counts the external pulse signal from the PULSE-pin and store the counted pulse values in TL0 (timer 0 low bytes) register. The maximum counting value of this internal Counter 0 is 255.

During the 'Gas Function' operation, if the START-pin signal is logic LOW, the whole operation will stop. If the B1-pin signal is logic LOW, the operation will switch to the baseline measurement operation. The sequence of gas measurement operation depends on the counted values in the TL0 register. At certain counted values in the TL0 register, a series of ASCII commands will be sent to the pump and valves. Table 1 shows the type of commands with their associated ASCII codes. To execute certain operation, a sequence of commands needs to be sent to the pump and valves. Table 2 depicts the commands involved with each type of operation.

Table 1- Types of commands with the associated ASCII codes

Types of command	ASCII codes
Open valve	O00, 0A, E, 0A
Close valve	F00, 0A, E, 0A
On pump	O01, 0A, E, 0A
Off pump	F01, 0A, E, 0A
Activate routing valve	O02, 0A, E, 0A
Deactivate routing valve	F02, 0A, E, 0A

Table 2- The sequence of commands involved in each operation

Operation	Command Sequence
Gas flow	• Open valve • Activate routing valve • On pump
Clean Flow cell	• Deactivate routing valve
Clean bottle and teflon tubing	• Activate routing valve
Off pump	• Close valve • Off pump

The operations run sequentially, beginning with the 'Gas Flow' operation followed by the 'Clean Flow cell', 'Clean bottle and teflon tubing' and lastly, 'Off pump'. Each operation takes 2s to send all the ASCII commands to the pump and valves.

As have been mentioned in the measurement procedure in section 2, the vapour measurement begins with opening the valve, activating the routing valve to the vapour inlet and turning on the pump. Then, the vapour inside the sample bottle is sucked in by the pump and it flows into the flow cell. This process occurs for 18s. After 18s, the routing valve is deactivated by routing it to the synthetic air inlet and the sensors inside the flow cell are cleansed for 78s. Then the routing valve is activated again by routing it to the vapour inlet for the bottle and the Teflon tubing cleaning purposes. This process takes 48s. Lastly, the process is stopped by closing the valve and turning off the pump. The total execution time for this gas function is 152s.

3.3 Air Function Subroutine

Similar to the Gas function subroutine, the Air function subroutine will call the serial and the counter functions. Figure 4 illustrates the air function flowchart. The Air function subroutine stops if the START-pin signal is logic LOW and control of the subroutine switches to the Gas function if B1-pin signal is logic HIGH. Since the Air function is meant for baseline measurement, the synthetic air is sent to the flow cell to get the baseline reading. The process begins with ‘Air flow’ operation, which occurs for 18s and then the process stops by the ‘Off pump’ operation. Table 3 depicts the types of operation involved and the corresponding ASCII commands. The reference ASCII codes are as listed in Table 1. The total execution time for the air function is 22s.

Table 3- Types of operations with sequence of commands for baseline measurement

Types of operation	ASCII Commands
Air flow	• Open the valve • Deactivate routing valve • Turn on pump
Off pump	• Close valve • Off pump

3.4 Display Function Algorithm

Figure 5 depicts the process flow for the LCD function in the e-nose odour sensor system. In this project, the LCD was used to display the current process involved in each measurement and the detected vapour. The types of text display on the LCD unit depend on the logic signal of the B1 switch. If B1 signal is logic HIGH, which is in the vapour measurement mode, the AT89C55WD will send data to display the detected vapour and the neuron output as well as the classification-score values. Additional processes involved during the vapour measurement mode such as ‘Cleaning flow cell in process’, ‘Cleaning bottle and tube process’ and ‘The pump is off end process’ are also being displayed.

If B1 signal is logic LOW, which is in the baseline measurement mode, the AT89C55WD will send data to display ‘Air Baseline measurement’ and the baseline frequency-shift values of the QCM signals.

The period of displaying each operation depends on the counted pulse values in the TL0 register, which is set at a pre-determined value. Figures 6 to 9 illustrate few samples of the display on the LCD unit during the measurement processes.

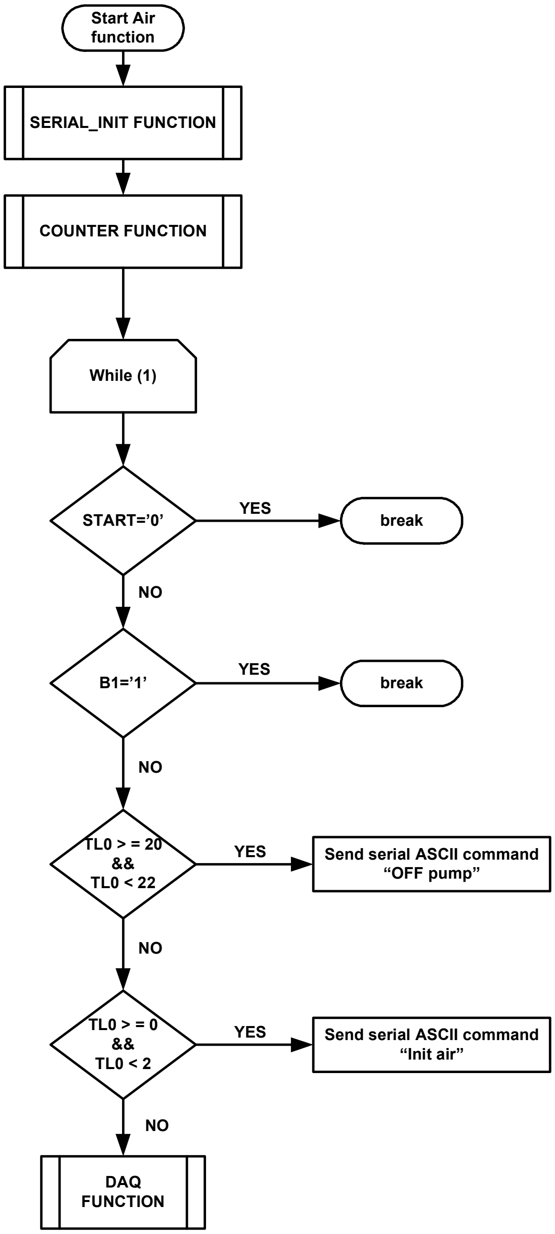

Figure 4 - Air function flowchart

3.5 Overall Sequence of Operations

The overall sequence of operations for both gas and air functions depend on the counted pulse values stored in the TL0 register. Tables 4 and 5 give the summaries of the counted value in TL0 register, the time required and the sequence of operations involved during the Gas and the air functions.

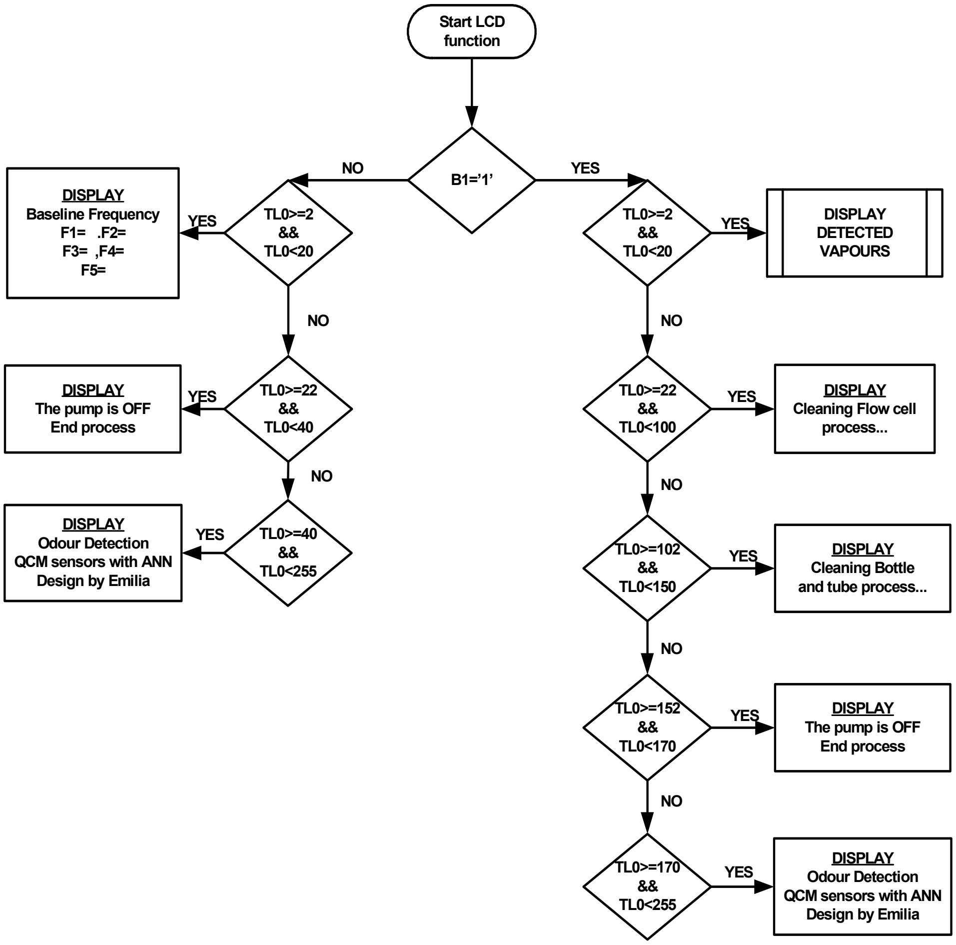

Figure 5- LCD function flowchart

Table 4- Gas function sequence of operations

Counter value in TL0	Time Required (s)	Operation involved
0 ≤ TL0 < 2	2	Send “Gas flow” ASCII commands
2 ≤ TL0 < 20	18	Display the detected vapour
20 ≤ TL0 < 22	2	Send “Clean flow cell” ASCII commands
22 ≤ TL0 < 100	78	Display “Cleaning flow cell process”
100 ≤ TL0 < 102	2	Send “Clean bottle and tube” ASCII commands
102 ≤ TL0 < 150	48	Display “Cleaning bottle and tube process”
150 ≤ TL0 < 152	2	Send “OFF pump” ASCII commands
152 ≤ TL0 < 170	18	Display “The pump is OFF. End process”
170 ≤ TL0 < 255	85	Display” Odour Detection. QCM sensors with ANN. Design by Emilia”

Table 5- Air function sequence of operations

Counter value in TL0	Time Required (s)	Operation involved
0 ≤ TL0 < 2	2	Send “Init Air” ASCII commands
2 ≤ TL0 < 20	18	Display the baseline frequency-shift values
20 ≤ TL0 < 22	2	Send “OFF pump” ASCII commands
22 ≤ TL0 < 40	18	Display “The pump is OFF. End process”
40 ≤ TL0 < 255	215	Display” Odour Detection. QCM sensors with ANN. Design by Emilia

```
Baseline Frequency
 F1:4571   F2:3774
 F3:3275   F4:7769
     F5:831
```

Figure 6- Baseline frequency-shift values

```
  Gas Chloroform
 Output:0.999168
   Score:99.91
```

Figure 7 - Detected vapour with neuron output results

```
Cleaning Flow cell
   process...
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Figure 8- Cleaning flow cell process

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Cleaning Bottle and
Piping process...
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Figure 9- Cleaning bottle and Teflon tubing process

4. Conclusion

The odour handling and delivery systems consisted of a flow cell, pump and valves which reside in the QTS-3 Instrument (Quartz Technology Ltd, UK) and the Teflon tubing was used in this e-nose system setup. The AT89C55WD Microcontroller had been successfully used to control the automated vapour and baseline measurement processes. The RS232 serial communication link was used by the AT89C55WD Microcontroller to send the ASCII commands to the pump and valves. The internal counter of the AT89C55WD Microcontroller was activated and used to count the external pulse signal generated from the Xilinx IC at every 1s, which is vital for correct timing of each process. The sequence of odour measurement processes was done according to the internal counter value pre-determined in the source code of the AT89C55 Microcontroller.

The design of an e-nose system with sample flow system and automated odour measurement process has produced a prototype of portable e-nose system capable of fast hazardous VOCs detection.

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