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Design of Measurement System for Vehicle Emissions in Real Road Conditions

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***Abstract*— The current paper describes a complex measurement system of the vehicle emissions which is based on electrochemical sensors for nitrogen oxides (NOx), carbon monoxide (CO) and sulfur dioxide (SO_2), photoionization detector (PID) for measurement of the volatile organic compounds (VOCs) levels and particulate matter (PM) sensor. The measurement data are displayed on an intelligent HMI LCD/TFT display with UART interface and capacitive touch screen and are written on SD card. Simultaneously all data are transferred to a remote server via GSM/GPRS modem or Bluetooth connection for real-time analysis.**

***Keywords*— vehicle emissions, PID, particulate matter**

I. INTRODUCTION (*HEADING 1*)

The vehicles are a major source of air pollution in urban areas. The main pollutant gases are recognized as nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HCs). Nevertheless of the engineering progress in the internal combustion engine construction the amount of the evolved harmful gases in the real road conditions are significantly depends on the driving style, car and engine technical condition as well as the quality of the fuels used in the internal combustion engines. Several methods are used to measure vehicle emissions, such as on-board emission measurements (PEMS), remote sensing, near-road air quality measurements, and tunnel studies [1,2]. Simultaneously the black carbon emissions also have to be measured as during the cold-start phase contributed 2%–33% to the total emissions [3].

The proposed complex measurement system from one side is based on the electrochemical sensors for NOx, CO and SO_2 gases, which are low-power, robust and low-cost, and are based on amperometric sensor to detect the selected toxic gases at the ppb levels in the industrial environment [4]. The system also integrates a photoionization detector (PID) with onboard regulator enabled for measurement of the volatile organic compounds (VOCs) levels and has a linear dynamic range of 1 ppb to 50 ppm (Isobutylene). The particulate matter emissions are also detected in the range 0.3-10μm in size and this range is divided in three main categories - 1.0μm, 2.5μm and 10μm. Additionally the sensor calculates the particle number at 0.1L air and distributes them in some categories - 0.3μm, 0.5μm, 1.0μm, 2.5μm, 5.0μm and 10μm. All data are sent to four endpoints such as remote server via GPRS connection, Bluetooth link and LCD/TFT display via UART interface and are written in the SD card for local storage.

II. SYSTEM DESIGN DESCRIPTION

The system block is shown at Figure 1 and consists of electrochemical sensors for the pollutant gases, GNSS receiver, SD card as a memory, the particulate matter (PM) sensor and temperature sensor to calibrate the electrochemical sensor values. The main vehicle emission include some main pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), different type of hydrocarbons, sulfur dioxide (SO_2) and particulate matter (PM). The hydrocarbon levels are detected by a photoionization detector (PID), which has an analog output. During the last few years lots of the semiconductor manufacturers [5-10] proposed signal conditioning circuits for the electrochemical sensor based on the potentiostatic circuit [5]. One of the possible solution of the measurement system is based on 4-electrode electrochemical sensors, in which 4th electrode is a correction for zero current and temperature zero current shift as the required gas concentration is in the ppb range. If the detection level is higher than the standard 3-electrode sensor may be used. When a working electrode is exposed to a target gas it produces an additional signal above the baseline which is proportional to the gas concentration, while the auxiliary electrode voltage is unaffected. The conversion of the differential voltage to the single ended one is accomplished by the Individual Sensor Board (ISB) designed by Alphasense. The working and auxiliary electrode signals of each sensor are amplified and the buffered signals are feed to the ISB output connector. All sensor boards are initially calibrated by the producer and the ISB gain and offset are written in the microcontroller memory. Designed for low power applications, the ISB requires 3.5 to 6.4 stable DC supply at only 1mA. Due to the very low noise design and the low output impedance of ISB board it may be connected to analog inputs of the microcontroller while the ADC

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REF+ pin is connected to 1.024V fixed voltage reference (FVR) to increase the analog-to-digital conversion resolution.

The power supply block (Fig.1) provides the output voltages of 5V to supply the electrochemical sensors, PID sensor, LCD/TFT display, particulate matter (PM) sensor and GNSS receiver, 4.0V for GSM/GPRS modem and 3.0V to supply the microcontroller, I^2C-UART converter and the SD card. As the GSM/GPRS modem I/O maximum voltage level is limited to 3V, the microcontroller supply voltage is set to this value to avoid the voltage level translators. This value is also appropriate to generate 1.024 or 2.048V for ADC REF+ pin by the built-in FVR block

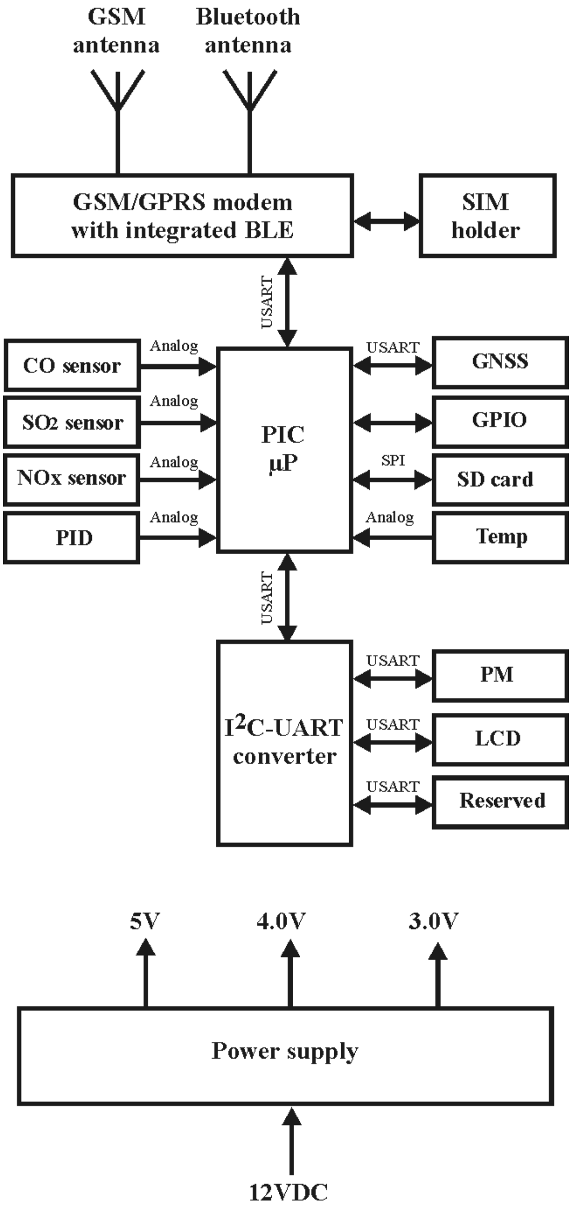

Figure 1. System block diagram

The particulate matters are measured by CP-15-A4-CG sensor, which is commercial grade laser-based sensor with digital outputs (UART and PWM) (Figure 2). The sensor is distinguished with a measurement range 0.3-10μm, 3.3V level outputs, PM2.5 consistency of ±10μg/m^3 or ±10% (which is smaller) and response time less than 3s [11].

Figure 2. PM sensor type CP-15-A4-CG

One of the great design challenges is defined from the obstacle that there are lots of devices which require UART communication such as LCD/TFT display, PM sensor, GSM/GPRS modem, CO2 sensor and GNSS receiver. As lots of the low cost 8-bit microcontrollers are equipped with up to two independent UART interfaces it is impossible to connect all devices to the microcontroller directly. If there UART interfaces are multiplexed then the data may be lost when the device sent data when the multiplexer channel is off. Also as the microcontroller I/O pins are only 3V compatible, the communication interface has to include level translators between PM sensor and LCD/TFT display and microcontroller. To overcome these connection problems the integrated UART interfaces are connected directly to GSM/GPRS modem and GNSS receiver and PM sensor, CO2 NDIR sensor and LCD/TFT display are connected to the microcontroller via multichannel I2C – UART converter which is shown at Figure 3. Each converter channel consists of single UART with slave I2C-bus/SPI interface ICs SC16IS740. This ICs is distinguished with 64 bytes of transmit and receive FIFOs and IrDA SIR built-in support. The UART interface is connected to the level translator for both RXD and TXD lines, which enables bidirectional voltage *level translation* between both power supply voltages. The I2C mode is selected if SC16IS740 I2C pin is set to high level. The SC16IS740 power supply is set also to 3V by the LDO regulator MCP1700T-3002 (Figure 3).

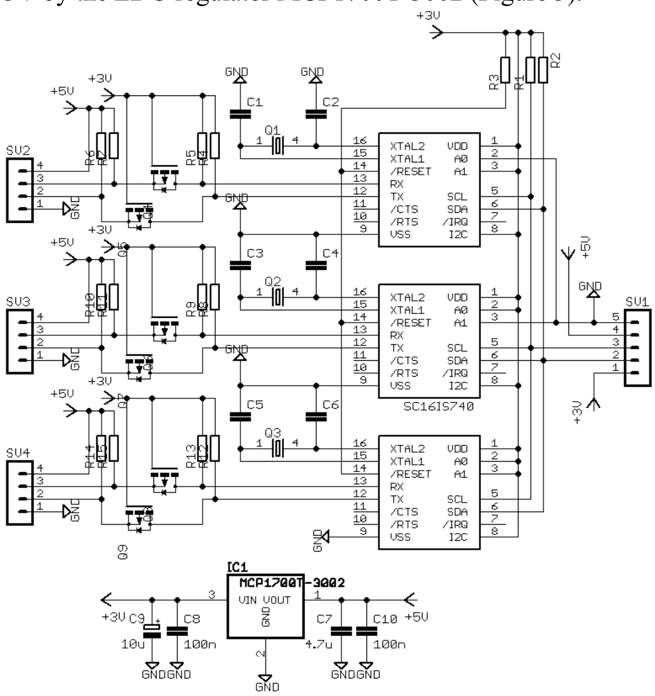

Figure 3. I^2C-UART converter schematic

All measurement data are sent to four endpoints (Figure 4). The first endpoint is 7-inch HMI (human-machine interface) TFT-LCD industrial display module with UART interface and capacitive touch screen produced by STONE company (Figure 5). This module has built-in Cotex-M4 32-bit CPU and may be controlled via the UART port with Hex instructions. The display producer provides the software engineers with lots of graphical user interface features such as video & audio, text, numbers, curves, images, USB download, progress bar, keyboard, data storage, slider, touch buttons, dial and clock.

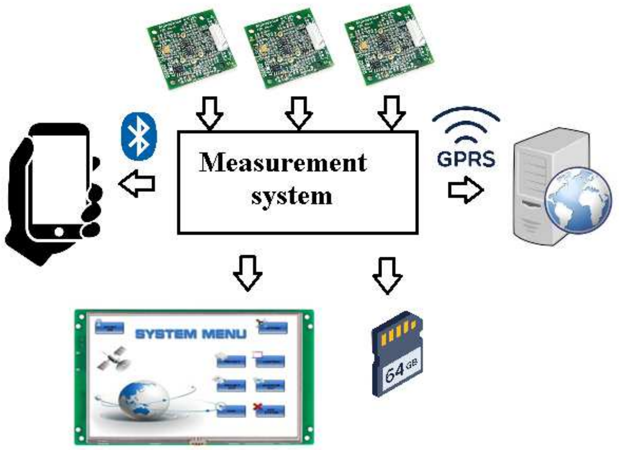

Figure 4. System endpoints and communication channels

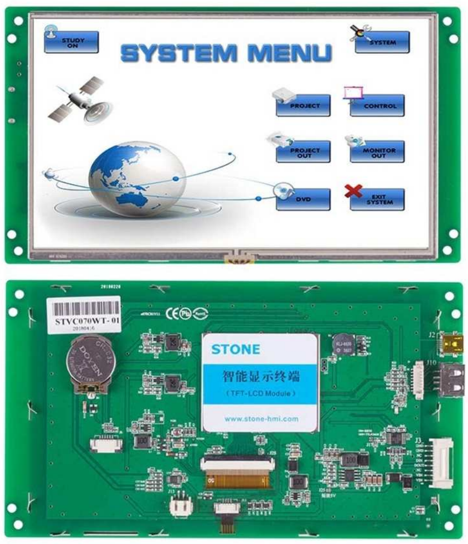

Figure 5. 7-inch HMI TFT-LCD industrial display module with UART interface

The complex measurement system requires to display the following data:

- CO, VOC, NOx and SO_2 level in ppm or %vol
- The measurement point position – WGS84 longitude / latitude
- Vehicle speed
- Temperature
- Particulate matter levels

The measurement page view in the development software is shown at Figure 6.

The second data endpoint is the integrated SD card, which is connected to the microcontroller MSSP2 interface at SPI mode. The transmission rate is up to 4 Mbps.

The third endpoint is the remote server where the measurement data are sent via GSM/GPRS modem using UDP packets.

The fourth endpoint is the mobile device installed in the vehicle where the data are sent via Bluetooth Low Energy (BLE) connection. The integrated BLE 3.0 in the GSM/GPRS modem uses Serial Port Profile (SPP) to connect to any mobile device and the data are readable in some serial terminal program or mobile application.

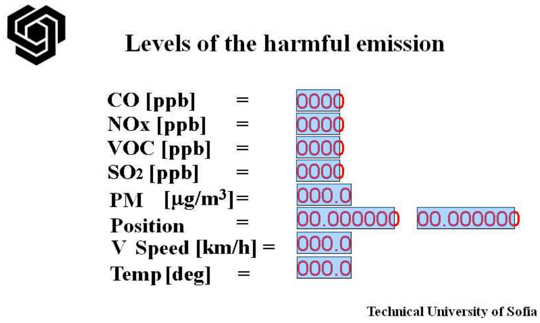

Figure 6. LCD/TFT panel visualization

III. RESULTS

As the system contains lots of electrochemical sensors, the paper represents only CO concentration and PM sensor data. The particulate matter sensor is situated nearby the vehicle exhausting tube and the gasoline engine works in two modes – idle and working ones. The results of the number of particles and the particulate concentrations are shown at Figure 7 and Figure 8 respectively.

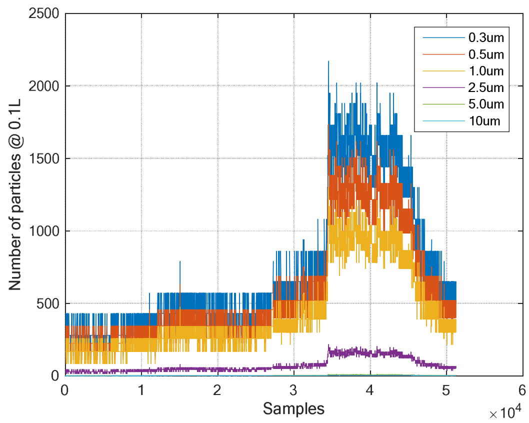

Figure 7. Number of particles at 0.1L air according the size

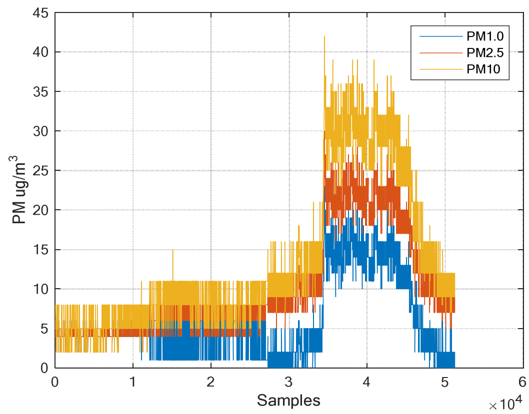

Figure 8. PM concentrations according to the particle size

During the engine idle mode the PM concentration is still low but the levels increased significantly in the working mode – up to three times. The particle numbers increased due to the increased fuel consumption and air-to-fuel ratio.

The CO sensor is a CO-B4 compact 4-electrode low ppb electrochemical sensor, which allows resolution up to 50 ppb and an operating range to 20ppm. As the sensor is mounted on the system and the power supply is applied, the sensor needs several hours for the sensor to stabilize in ambient, clean air (Figure 9)

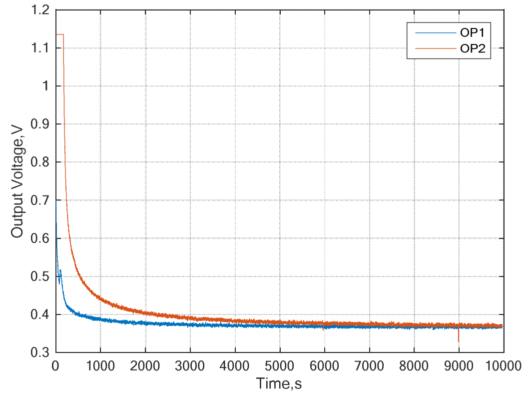

Figure 9. Sensor output voltage vs Time

As the sensor output voltages (reference electrode voltage OP1 and working electrode voltage OP2) are stable in time (Figure 10)., the output voltage ripple is measured to evaluate the system noise and calculate the gas concentration according to the voltage difference, zero currents, zero offset, sensor sensitivity and temperature corrections [12].

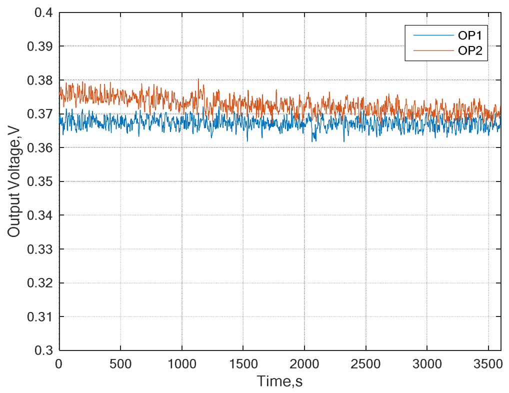

Figure 10. Sensor output voltages (OP1 and OP2) in the ambient clean air

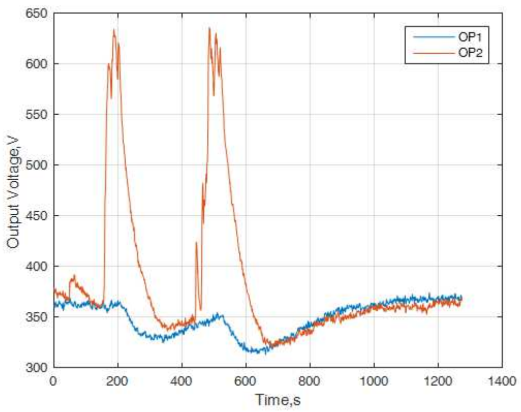

Figure 11. Sensor output voltage during test

The sensor concentration during the test is shown at Figure 11. The idle and the working modes are also well distinguished and the sensor OP1 voltage is increased from 370mV to 630mV. According to the sensor sensitivity of 478mV/ppm, this voltage change corresponds to CO concentration of 0,55ppm.

IV. . CONCLUSION

The proposed system allows to measure the levels of the harmful cases emitted by vehicles in real – time situations and number of fine particles in the air which are responsible for many respiratory diseases. As the vehicle emissions are significantly increased in the real urban situations compared with the test conditions, the real road emission measurements allow better evaluation of the vehicle air pollution. The combination of the sensors and GNSS receiver also allows to create a pollution map which may accessed by Internet as the data are sent to the remote servers. In the same time all data may be monitored locally due to the connected LCD/TFT display and BLE connection.

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