μVOC – A lightweight environmental data and air samples acquisition system to install in captive balloons

José Fonseca[1], Francisco Carreiro[1,2], Valter Silva[3,1],
Margarita Evtiouguina[4], Miguel Marques[4], Cláudia Albuquerque[4]

[1]DET, University of Aveiro, Campus Universitário Santiago, 3810-193 Aveiro, Portugal, jaf@det.ua.pt
[2] DEE/CEFET, Avª Getúlio Vargas Nº4, Monte Castelo, 65025-001 São Luís-MA, Brasil, fborges@ieeta.pt
[3] ESTGA, University of Aveiro, Zona Industrial da Alagoa, Ap 473, 3754 – 909 Águeda, Portugal, vfs@estga.ua.pt
[4] DAO, University of Aveiro, Campus Universitário Santiago, 3810-193 Aveiro, Portugal, margarita@doa.ua.pt, {fmmarques, albuquerque}@aeiou.pt

***Abstract*— One of the current research work in environmental science is the study of the impact of polluting substances such as Volatile Organic Compounds (VOCs) generated in coastal regions where human activity is more intensive in inland regions. In fact, due to maritime breezes, the effect of pollution is often sensed far away from the local that originates it. The VOCs distribution depends on the height and meteorological parameters, such as temperature, pressure and relative humidity. Therefore these parameters must be measured in a vertical plan to a correct pollution characterization.**

In this paper a specific small system for acquiring VOCs and meteorological parameters is presented. The system was developed in order to be suitable for use in a small helium balloon with low weight capacity. No electronic commercial system is available with the desired characteristics for this purpose. The system is lightweight, acquires product samples with constant airflow control, and performs temperature, pressure and humidity data acquisition. The system uses a small microcontroller and some specific techniques to avoid loosing data during operation. It is also a very low-cost system which is an important issue due to the high risk of damage or lost. The paper describes implementation details and results from the experiments carried on with the prototypes.

***Index Terms*—embedded systems, data acquisition systems, meteorological parameters sensing, environment monitoring.**

I. INTRODUCTION

In coastal regions, the generation of polluting substances by human or natural activity can give origin to local or regional pollution phenomena. During summer periods, the presence of maritime breezes with circulation patterns that recirculate air masses during a consecutive number of days, can increase the production of secondary pollution. The regulatory mechanisms of the chemical reactions are a function of the height and so are the concentrations. It is thus important for environmental pollution monitoring to determine vertical profiles of the concentration of such substances, in particular VOCs [1], i.e., volatile organic compounds, as well as of meteorological parameters such as temperature, pressure and relative humidity.

In this field of application the data acquisition is done with the help of a captive helium balloon, which will be released till a specified height [2]. During this operation, data must be acquired at different heights and samples of

VOCs must also be automatically obtained. The associated equipment must be light due to the limited capacity of the available balloons.

The unavailability of specific equipment to do this operation led the research teams of the Electronics and Environment departments of the University of Aveiro to join efforts to develop, test and apply a light weight microprocessor based system, called μVOC. This system presents some simple but original solutions to better adapt the microprocessor to the tough operating environment.

In this paper, the development and test of the μVOC system is described. The paper starts in section 2 describing the problem, the experimental set-up and the operating environment. Also, the data acquisition requirements are identified there. In section 3 the electronic system architecture is presented. This includes the identification of the elements of the system, the HMI (human machine interface) and the hardware blocks. In section 4 the operation of the system is discussed. In section 5, the calibration of the system is explained and discussed. In section 6, the laboratory tests, the field trials and the respective results are presented and discussed. These validate the assumptions made about the system operation but show also some improvements that must be done in some of the circuits. Finally the paper ends, in section 7, with some conclusions and a brief discussion of future work in this area.

II. THE EXPRIMENTAL SETUP REQUIREMENTS

The μVOC system is one of the instruments to be mounted in a captive balloon. In our case, a TSB-5 balloon from Vaisala [3] company was chosen. This Helium balloon, with its 5m^3 capacity and the shape similar to a Zeppelin balloon is able to carry a 2.7kg load. However, the weight of the cable must also be taken into consideration. For 1.000 meters, the adequate cable must have 0,95g.m^{-1}, which leaves 1,7 kg for all the instruments.

The system must be able to measure some environment

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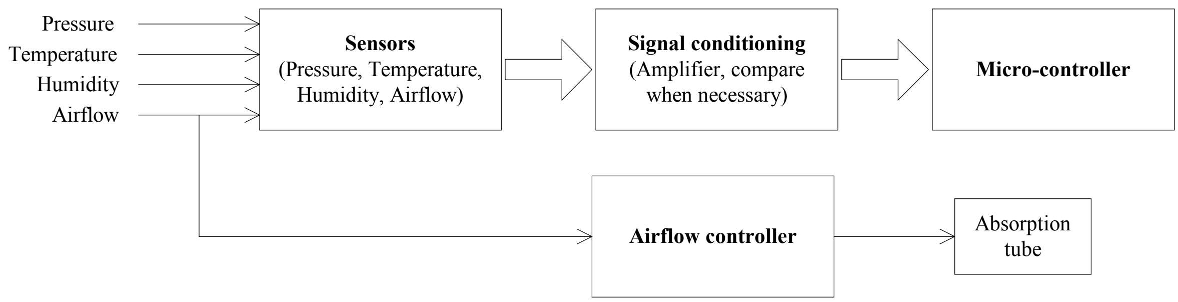

Figure 1 – System architecture

variables [4], which are presented in table 1. In addition, it is necessary to collect air samples to evaluate the VOCs quantities. In order to do this, a small air pump is used to maintain constant (100 ml.m^{-1}) airflow in a pipe.

The complete system is composed by three µVOCs fixed at the balloon cable in different heights, for a vertical characterization of the environment.

III. System architecture

The µVOC system consists in a human machine interface running in a PC computer and an embedded system to install in the balloon which includes a microprocessor-based board and two analog subsystems: the measuring unit and the flow control unit.

Table 1 – System requirements

Measurement Variable	Operation Range	Precision
Pressure	1050 - 850 hPa	±0,5 hPa
Humidity	10 (or 20) - 100 %	±2 %
Temperature	-20 - +40 ºC	±0,2 ºC

The measuring unit includes the pressure, humidity/temperature and flow sensors and the respective signal conditioning analog electronics based in instrumentation amplifiers and specific circuits (e.g. Wheatstone bridge for the temperature sensor). A SX15AD sensor from Sensym, Inc [5] is used for pressure, a Honeywell HIH-3602-C sensor [6] that includes a platinum RTD is used for humidity and temperature, and an AWM3100V [7] also from Honeywell is used for airflow control.

The HIH-3602-C humidity and temperature sensor has internally two independent circuits to measure humidity and temperature. The humidity sensor consists of a sensitive to humidity polymer. The temperature sensor is a heat sensitive resistor formed by a platinum film. This resistor is part of the external Wheatstone bridge used to measure the absolute temperature. The temperature and humidity sensors are thermally connected making a single device. Since the relative humidity varies with temperature and considering the physical proximity of these two sensors, it is possible to use a law to determine the relative humidity.

The temperature sensor is just one platinum resistor, and is mounted in a Wheatstone bridge with more three 1K resistors (the RTD in environment temperature has approximately 1K of resistance). The signal output of the bridge must be amplified about 11 times with an AD623AN instrumentation amplifier.

The SX15AD is a pressure sensor specially designed to be used with non-corrosive and non-ionic media, such as air and dry gases and can be used for measuring pressure from zero up to 15 psi. The SX15AD has an internal vacuum reference and an output voltage proportional to the absolute pressure applied in its pressure port. The output voltage isn't amplified and an amplifier must then be used. The amplifier, also based in a AD623AN, magnifies the signal 11 times.

The airflow sensor AWM3100V operates based on the principle that the airflow directed across the surface of a sensing element causes heat transfer. Output voltage varies in proportion to the mass of air or of other gas flowing through a given inlet and outlet ports of the sensor. The gas flowing through the sensor must be free of condensing moisture and particle contaminants otherwise the sensor will be damaged. An inexpensive 5-micron filter upstream of the sensing element substantially reduces this risk. The output voltage of this sensor is already amplified, and so, it is possible to use directly the output signal in the hardware control loop.

The flow control unit uses the flow signal from the AWM3100V sensor and a diaphragm micro pump model NMP09L from the KNF Company. The air pump used is a miniature diaphragm air pump activated by a small electrical motor. Due to the type of pump the airflow obtained is extremely nonlinear. This problem is solved by a sort of mechanical filter obtained by inserting a piece of cotton in the tube that connects the flow sensor and the pump and by an adequate electronic control system, presently analog in order to avoid the processing overhead in the embedded microcontroller. The block diagram of the airflow control system is shown in figure 2.

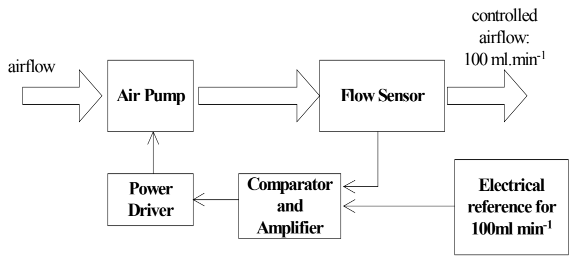

Figure 2 – Airflow control systems

As it can be seen in figure 2 a reference voltage (in this case tuned to 100ml.min^{-1}) is fed to a comparator and an amplifier block. The airflow sensor feeds the other comparator and amplifier input. The difference is controlled by an adjustable gain in the output of the block and applied to the power drive block input. The comparator and amplifier block is composed of an AD623AN instrumentation amplifier and its external components, i.e one resistor to impose gain, resistors and capacitors to implement a filter to eliminate the electromagnetic interferences.

The power driver is composed of two IRF 510 N channel MOSFETs mounted in series. One MOSFET is used like an on/of switch controlled by the microcontroller and the other MOSFET regulates the AC voltage over the pump according to the voltage from the comparator and amplifier block, in this way controlling the airflow in the system.

The figure 3 shows the electronics for acquisition, signal conditioning and airflow control described before.

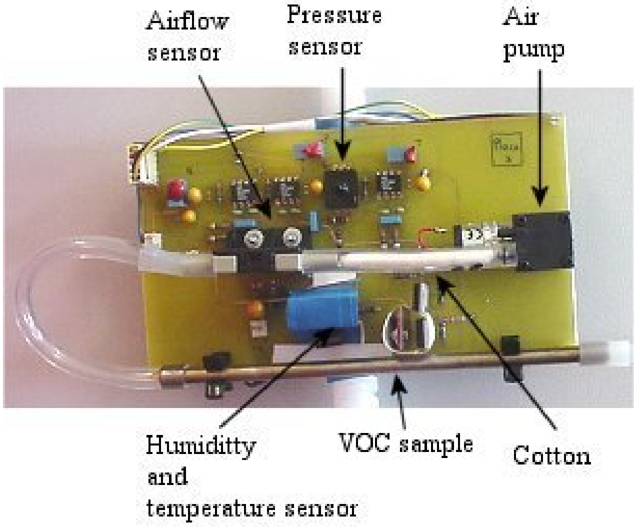

Figure 3 – µVOC system

The microprocessor-based system uses just a 28 pins Microchip PIC16F876 microcontroller [8]. This component includes 8Kb of program memory, in flash, 368 bytes of RAM and 256 bytes in an EEPROM. Several interfaces such as a serial port and three 8 bit parallel I/O ports are also included. Three timers, one Watchdog, two PWM generators and a 10-bit A/D converter with five input channels are also available in the microcontroller. Our system operates with a 20MHz oscillator, the maximum operating frequency for the device.

The embedded system is powered from a 104 grams pack with 8 Ni-MH rechargeable batteries (9,6 V / 750 mAh, shown on the right in figure 3) and a set of voltage regulators that generate 8V for some of the sensors and 5V for the other equipment.

IV. SYSTEM OPERATION

The system uses a 1 second clock tick signal to generate the sampling period of the physical parameters (temperature, humidity, pressure). The sampling periods can be programmed prior to the launching of the system recurring to the off-line operation software that runs in a host PC computer. Each data unit consists in the following information:

- The physical quantity (e.g. temperature).
- The sample value.
- An offset in seconds from the start of the system operation.

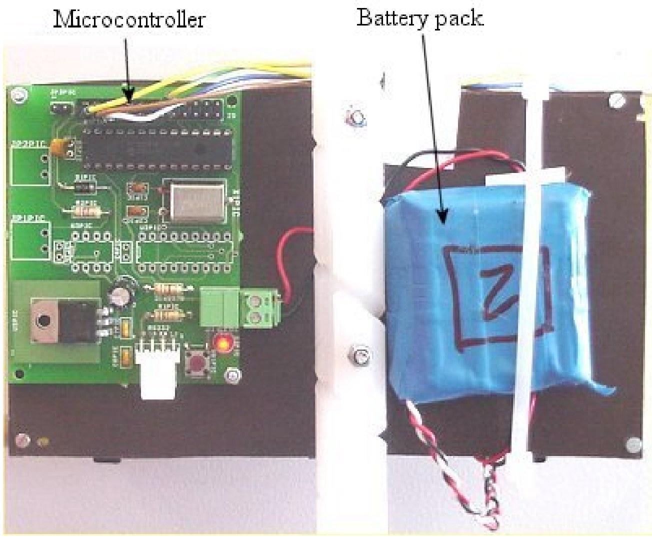

Figure 4 – Microprocessor and battery

The system uses a clever solution to simplify the data storage and to achieve the robust operation and fault tolerance required, considering the harsh environment where it operates. First of all the data is stored in the program flash of the microcontroller. The start address and, consequently, the system autonomy are computed during the firmware preparation. This solution prevents the occurrence of lost data if the system battery fails. Secondly, the system is prepared to support resets without loosing its operation conditions. The watch dog (a manual reset can also be tolerated) can then be used to reinitiate the system if it stops when subject to EMI. To do this the software works using state conditions and values also stored in the flash memory.

The system uses then three operating states:

- Stopped
- Initialized
- Operating

The system enters the "Stopped" state when it starts operating firstly or after it has successfully finished an operation cycle. The system leaves this state with a specific start command issued by the PC-based operation software.
The sampling procedure requires that all the µCOVs collect an air sample at the same moment. For this purpose, it is possible to configure a variable time interval between the start command and the beginning of the operation cycle, which also accounts for the time of programming and preparation on the ground and of the balloon ascension.

During the "Initialized" state the system is just waiting for the configured interval to elapse. Again, the elapsed time is kept in flash to enable the possibility of resets or restarts of the software program.

Finally, the system enters the "Operating" state when the interval elapsed. During this state the system acquires data from the available input channels according to a configuration (channel ON/OFF, period, offset after start of operation, etc.). The system can also be instructed to perform other simple operations such as switching ON or

OFF the pump and valve of the subsystem to store air samples. This data is also stored in flash.

During the configuration it is also possible to setup the duration of the "Operating" state. The system switches to the "Stopped" state whenever the programmed time has elapsed.

During the "Stopped" state the system can be accessed from the PC-operation software. The data in the flash can then be uploaded prior to the next start command. A capture of this software is shown in figure 5. This program is also necessary to program the different offsets and sampling periods of the system. The serial port is used to communicate between the PC and the µVOC.

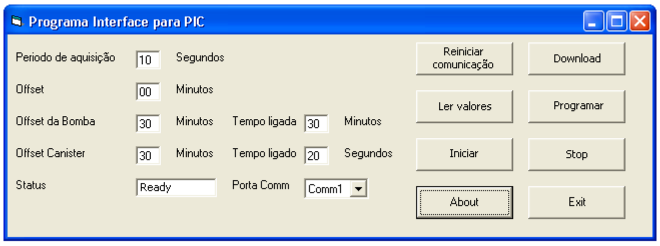

Figure 5 – Program interface to manage µVOC system

V. SYSTEM CALIBRATION

The measurement system only outputs to the microprocessor an electrical signal. This electrical signal, in the range 0-5V, must be converted to a digital value and after stored in the microprocessor memory. The microprocessor used has one internal successive approximation ADC with 10 bits of resolution. With the used range, and with this ADC, a resolution of $5/2^{10}$V is obtained. As there is not a direct reading of the physical variables and as the sensors can show some, although minor, differences, a calibration procedure is required for every µVOC system.

I. Pressure

Each one of the four pressure sensors in the four systems, have been calibrated according to an experimental setup [4] that uses a precision barometer [9]. This barometer has less than 1 mbar of precision and has a range of 1 to 1100mbar. Six points covering all the necessary range of pressure were used in this procedure. The resultant graphic is shown in figure 6.

II. Temperature

The calibration of the temperature was done using a room with controlled temperature and a system from TestoTerm [10] for reference. In figure 7 the result of the calibration for all systems is shown.

III. Humidity

For the calculation of the relative humidity, the expression provided by the manufactured of the sensor [6] was directly used:

$$RH[\%] = \frac{V_{out}[mV] - 800}{32.6926 - 0.06696 * T[^{\circ}C]} \qquad (1)$$

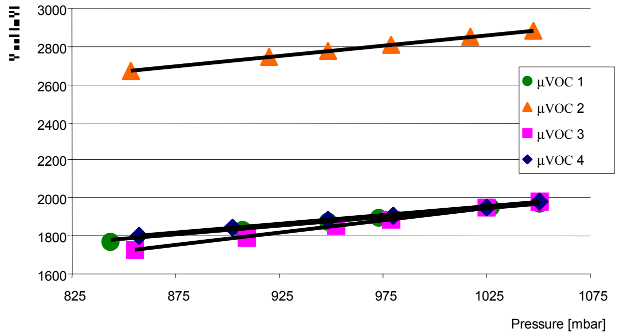

Figure 6 – Pressure calibration

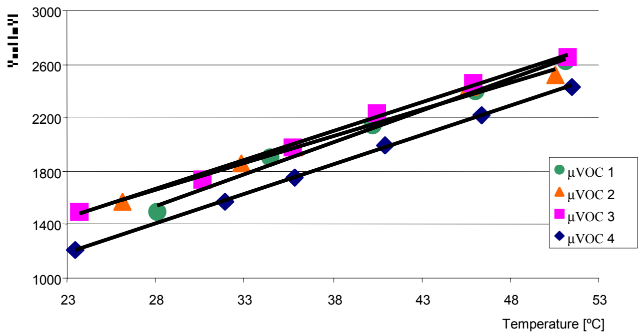

Figure 7 – Temperature calibration

VI. FIELD TRIALS OF THE µVOC SYSTEM

The system was subject to a set of laboratory trials to evaluate its operation and to test its performance under resets. The microcontroller-based unit was also mounted in a field trial with the balloon. The operation was successful with samples being taken adequately. The µCOVs were used intensively during a one week field campaign in Aveiro. During this period they were used on a regular basis to acquire meteorological data and to collect air samples. In what would be the last day of the campaign, the balloon was lost due to an equipment defect. The balloon company is now supplying another unit and the field trials will be resumed as soon as possible. However, this fact does not jeopardize the results from the electronics point of view but only prevented the Environment Department team to complete the field campaign and to compare and analyze the results.

In figure 8 it is shown an example of temperature and humidity data obtained by the µVOC at Aveiro University in September 25, 2002. The sample period is 5 seconds for both variables and the experience started at 10 AM.

During the field campaign the VOCs were collected for posterior analysis. The results are shown in figure 9.

The vertical profiles of VOC concentrations, for the major part of the compounds, revealed their general tendency to decrease with altitude. However, in several air monitoring experiments, performed specially in the morning or evening periods, the amounts of certain VOCs increased with the altitude (β-pinene, Figure 9). These were very interesting results for environmental research.

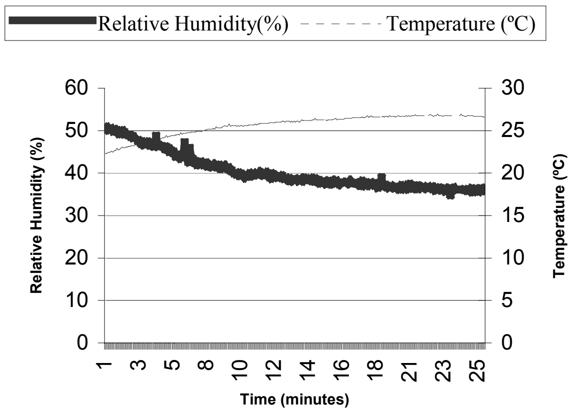

Figure 8 – Temperature and humidity acquisition

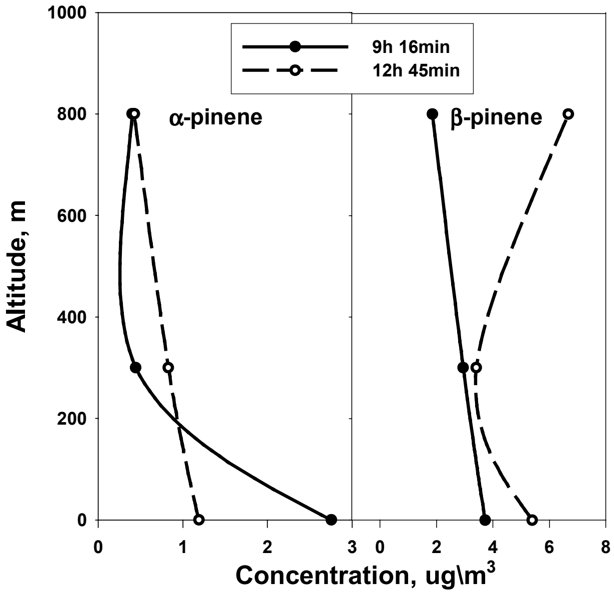

Figure 9 – VOC concentration

VII. Conclusion

In this paper a new system for a specific application in environment monitoring was presented. It consists in a lightweight system for the acquisition of air samples and environmental data to install in captive balloons. Due to the absence of adequate commercial products, this system was developed as an in-house solution for the scientific research activities ongoing at the University of Aveiro.

The system is composed by a low cost micro-controller and some additional electronics for signal acquisition and processing and an air flow control subsystem to collect air samples. The specific program developed for the micro-controller shows a reduced memory footprint. This turns possible to use the program flash memory to store measurement data. It is then possible to obtain autonomy of 10 hours with a sampling period of 30 seconds. Also, the use of this non-volatile memory and of a state of operation approach makes the system very robust to power failures or restart situations. This is a fundamental property considering the harsh operational environment for the system.

At the current development stage, additional field trials and assessments of acquired data are required to fully validate the system. One of the future lines of development is to study the integration of a very lightweight, very low power transmission unit. This unit would make easy on-line data monitoring during the field trials. An increase in the robustness of the electronics including the protection from adverse meteorological conditions (sun incidence, water condensation, for example) is also being considered.

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