A low cost and portable device for home care breath sensing

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Abstract. Here we discuss the first implementation of *Wize Sniffer 1.x* (WS 1.x), a portable electronic device for breath analysis in home care. The device is still a prototype which is being developed in the framework of the Collaborative European Project SEMEOTICONS (SEMEiotic Oriented Technology for Individuals CardiOmetabolic risk self-assessmeNt and Self-monitoring[1]). Some of the detected breath molecules are associated with cell metabolism, thus WS 1.x can give useful information about the state of health of an individual. WS 1.x can also give feedbacks about those noxious habits for cardio-metabolic risk, such as alcohol intake and smoking habit.
The low cost and compactness of the device allows for a daily screening of the general state of health of an individual that, even if without a real diagnostic meaning, could represent a sort of pre-monitoring that could be used for an optimal selection of more sophisticated and standard medical analysis.

Keywords: Healthcare, Breath Analysis, Portable Device, Gas Sensors, Signal Processing.

1 Introduction

Human breath is composed of nitric oxide, oxygen, water vapor, carbon dioxide, and numerous Volatile Organic Compounds (VOCs). The type and number of the VOCs in the breath of any particular individual will vary but nonetheless there is a comparatively small common core of breath which is present in all humans[1–6]. These VOCs may have:

– *Exogenous origin*: i.e, from inhaled air, from dermal absorption, from foods and beverages.

[1] http://www.semeoticons.eu, grant N. 611516

– *Endogenous origin*: they are produced by anabolic or catabolic reactions that occur in tissues or cells throughout the body.

About 35 of the identified compounds in the exhaled breath have been established as biomarkers for particular diseases and metabolic disorders [1]. It means that any variation (with respect to standard values) in VOCs' concentration levels may be an index of some diseases, or, at least, of metabolic disorders.

Breath gases have been identified as biomarkers using instrumentations such as gas chromatography (GC) or electronic nose (E-nose) [6]. GC, the gold standard for gas analysis, is very accurate but expensive, time consuming and non portable. E-nose is low-cost, but is not specifically useful for the analysis of breath molecules and hence has a limited application in medical field. Consequently, in recent years the need for a low cost, portable device for breath analysis has emerged. This device should be also easy to use, feasible for patients living far from medical structures or physicians and sufficiently accurate for the typical gas concentrations of human breath.

In this work, we introduce the design and functionality of the first prototype of a portable device for breath analysis limited to an effective number of substances, the so-called WS 1.x. In particular, (i) the design of the hardware platform, (ii) the implementation of the communication protocol between the device and a laptop, (iii) the functionality of the WS 1.x are described.

2 Analyzed gases

Our attention, within the SEMEOTICONS (SEMEiotic Oriented Technology for Individuals CardiOmetabolic risk self-assessmeNt and Self-monitoring) project, has been focused on Atherosclerotic Cardiovascular Diseases (ACDs). Then, the WS1.x has been developed to detect the breath compounds associated to the noxious habits for cardio-metabolic risk [4]:

– ***Carbon monoxide*** (CO). *Endogenous*: it acts as a cellular messenger and abnormalities in its metabolism have been linked to a variety of diseases, including neurodegenerations, hypertension, inflammation. *Exogenous*: it is the major component of tobacco fumes (75,95%). Its baseline level (BL) in a healthy subject is about 0.6-4.9ppm.
– ***Hydrogen*** (H_2): it results from carbohydrate fermentation by anaerobic bacteria into caecum and/or by oropharingeal bacteria. Increased values of breath hydrogen may be due to lactose intolerances, intestinal disorders, or an improper life-style. Its BL in a healthy subject is about 0.3-34ppm.
– ***Ethanol*** (C_2H_6O). *Endogenous*: originated from microbial fermentation of carbohydrates in the gastrointestinal tract. *Exogenous*: deriving from alcoholic drink. Ethanol causes accumulation of free radicals, resulting in oxidative stress. Its BL in a healthy subject is about 0-3.9ppm.
– ***Ammonia*** ($NH3$). *Endogenous*: elevated breath ammonia could be due to liver or kidney disease. *Exogenous*: it is a component of tobacco fumes

(about 22%); When inhaled, ammonia irritates the upper respiratory tract up to trachea. Its BL in a healthy subject is about 0-1.3ppm.

– ***Carbon dioxide*** (CO_2) and ***Oxygen*** (O_2). Exhaled air has a decreased amount of O_2 and an increased amount of CO_2, thus showing how much O_2 is retained within the body, and used by the cells, and how much CO_2 is produced as a by-product of cellular metabolism. Higher/lower values may be due to respiration disorders. $CO_2$is also one of constituents of tobacco smoke (about 13%). CO_2 and O_2 BL in a healthy subject are respectively about 4% and 13%.

3 Wize Sniffer 1.x's hardware and software architecture

A general scheme of the WS 1.x' s architecture is shown in Fig. 1 .
The core is an Acquiring Device (AD), a dedicated embedded hardware, includ-

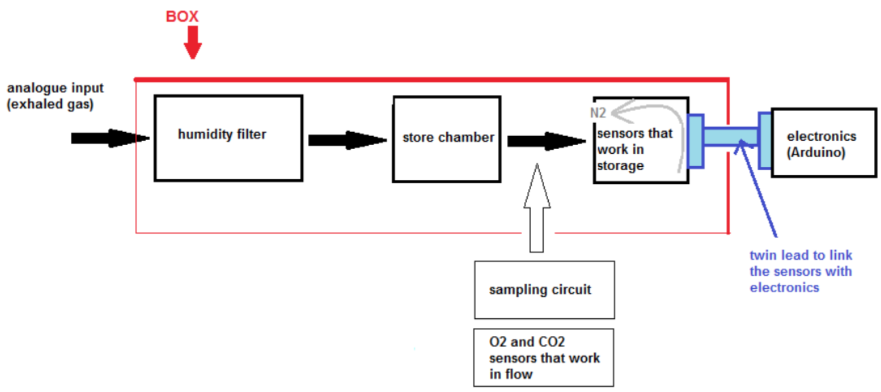

Fig. 1. Schematic sketch of the WS 1.x's architecture

ing a corrugated tube through which the gases flow, a gas sampling box where six gas sensors are placed, and a micro-controller board. Since the sensors' output is affected by the water vapor present in exhaled gases, a Heat and Exchange Moisturizers (HME) filter is placed at the beginning of the corrugated tube. In addition, the humidity percentage is monitored within the sampling box, as well as the temperature. Other two gas sensors having shorter response time work in *flowing-regime* by means of a sampling pump.
The sensors' output signals are read by a micro controller board. Table 1 lists all the commercial sensors used in the WS 1.x's architecture. As micro-controller board, an Arduino Mega2560 has been chosen, taking into account (i) its Analogue-to-Digital converter resolution for each input pins; (ii) the number of analogue input pins; (iii) availability of ethernet connection; (iv) SRAM capacity.

The WS system operates in three phases: gas collection, gas sampling, and

Table 1. Gas sensors and Temperature and Humidity sensor used in WS 1.x

Sensor	Detected compounds
Figaro TGS2602	Hydrogen, Ammonia, Ethanol, Hydrogen Sulfide, Toluene
Figaro TGS2620	Hydrogen, Carbon Monoxide, Ethanol, Methane, Isobutane
Figaro TGS821	Hydrogen
Figaro TGS4161	Carbon Dioxide
Figaro TGS2442	Carbon Monoxide
Figaro TGS2444	Ammonia
City Technologies MOX20	Oxygen
Servomex IR1507	Carbon Dioxide
Sensirion SHt11	Temperature and Humidity

data analysis. Once the gases are collected, the sampling process begins: the analytes are injected into the store chamber, where the gas sensors are placed, and changes in sensors' internal resistances are read and recorded by the Arduino micro-controller board. Then, a purge cycle allows to supply background air to the gas sensors to refresh the baseline measurement.

What makes the WS a portable device is, above all, the communication

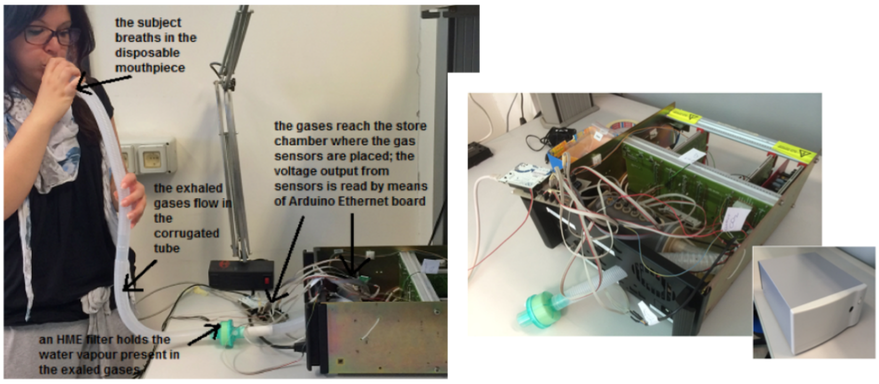

Fig. 2. WS 1.x final set-up

protocol between the Personal Computer and the device itself.
Indeed, in order to receive the data from the AD even on a remote Personal Computer (PC), we use a client-server architecture. In particular, the AD executes a daemon on port 23, waits a command line from the PC and provides the data, that means the outputs from the several sensors.
This approach allows us to use a dedicated unit for each task. Indeed, the AD works as dedicated hardware which collects and records the data; the computational capacity of a PC is used to analyze the data and calculate the gas

concentrations.
The final set-up of WS 1.x is shown in Fig. 2.

4 Results and discussion

Some preliminary tests were carried out on a small population of healthy subjects in order to evaluate the performances of the WS 1.x.
An example is shown in Fig. 3. The typical trends of "exhaled breath curves"

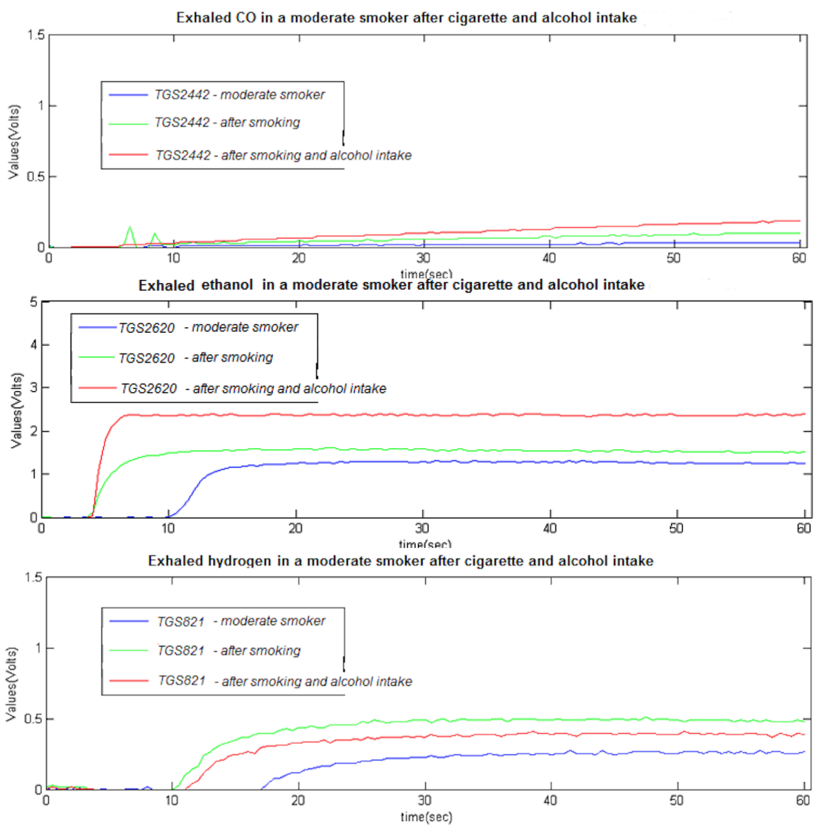

Fig. 3. An example of an outcome of a test. The test was carried out on a moderate-smoker, social drinker, healthy subject, female, in the age range (20-29), having normal body type, practicing sport 2 times a week. The subject breathed before and after smoking, and before and after smoking and drinking alcohol. WS 1.x was able to follow the trend in time of smoking (see exhaled CO detected by TGS2442) and alcohol intake (see exhaled Ethanol detected by TGS2620) . Not only, exhaled Hydrogen (detected by TGS821) showed an increase after smoking and a decrease after drinking alcohol, in agreement with the literature [5]. Temperature and humidity values ranged between 23-25 °C and 50%-60%, respectively.

can be seen: a few seconds after the sensors sense exhaled gas particles, the sensors' internal resistance varies, resulting in a voltage output rise, until the plateau curve. When the store chamber is purged, the voltage values come back (more or less slowly) to zero.
Further tests demonstrated that, from a qualitative standpoint, the WS1.x can discriminate the different alcoholic grades, and it is able to follow the trend in time not only of the alcohol intake but also of the alcohol disposal. In addition, WS1.x is also able to discriminate also between smokers and non-smokers.

Further studies and investigations are being carried on in order to develop a non-linear equation model able to calculate breath molecules concentration accurately, also overcoming the weakness of the semiconductor-based gas sensor, that is the cross-sensitivity.
In order to improve the gas sensors' sensitivity, (and overcome, for example, low response time as the TGS2442's one) the development of a new version of the WS based on electrospun nanofibers [7] will be our great future challenge.

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