A low cost, portable device for breath analysis and self-monitoring, the Wize Sniffer

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Abstract. Here we describe the implementation of the first prototype of the *Wize Sniffer 1.x* (WS 1.x), a low cost, portable electronic device for breath analysis. The device 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]). In the frame of SEMEOTICONS project, the Wize Sniffer will help the user monitor his/her state of health, in particular giving feedbacks about those noxious habits for cardio-metabolic risk, such as alcohol intake and smoking.
The low cost and compactness of the device allows for a daily screening that, even if without a real diagnostic meaning, could represent a pre-monitoring, useful for an optimal selection of more sophisticated and standard medical analysis.

Keywords: Healthcare, Breath Analysis, Portable Device, Gas Sensors, Signal Processing, Self-monitoring

1 Introduction

Human breath is composed of nitric oxide, oxygen, water vapor, carbon dioxide, and numerous Volatile Organic Compounds (VOCs)[1–6]. These VOCs may have *exogenous origin* i.e, from inhaled air, from dermal absorption, from foods and beverages, or *endogenous origin* i.e, products of 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 baseline - BL- values) in VOCs' concentration levels may be an index of some diseases, or, at least, of metabolic disorders.

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

Breath gases have been identified as biomarkers using gas chromatography (GC) especially[6]. GC, the gold standard for gas analysis, is very accurate but expensive, time consuming and non portable. Another approach for gas analysis exploits Electronic Noses (E-noses)[6]. They are low-cost, and easier to use, but they are designed for broader applications (environmental, industrial ones), rather than for medical field. Recently, Toshiba (http://www.toshiba.com/tai/) has developed a Breathalyzer for exhaled acetone, as well as Bedfont's Smokerlyzer and NOBreath (http://www.bedfont.com) which detect, respectively, exhaled Carbon Monoxide and exhaled Nitric Monoxide. Nevertheless, all these devices exploit expensive approach for gas detection (i.e., quantum cascade laser, infrared laser, optical sensors, ecc.).
Consequently, the need for a low cost, portable device for breath analysis has emerged. This device should be also easy to use, also in household environment, and sufficiently accurate for the typical gas concentrations of human breath. In this work, we introduce the design and functionality of a prototype of a portable device for the analysis of a limited number of breath molecules, the so-called Wize Sniffer (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, in the frame of the SEMEOTICONS project, has been focused on the prevention of 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 (alcohol intake, smoking) [4]:

- ***Carbon monoxide*** (CO): abnormalities in endogenous CO have been linked to hypertension or inflammation. It is also the major component of tobacco fumes (75,95%). Its 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 into oropharingeal tract. Increased values may be due to lactose intolerances, or intestinal disorders. Its BL in a healthy subject is about 0.3-34ppm.
- ***Ethanol*** (C_2H_6O): it derives from alcoholic drink, causing accumulation of free radicals and oxidative stress. Its BL in a healthy subject is about 0-3.9ppm.
- ***Ammonia*** ($NH3$): it is a component of tobacco fumes (about 22%); its BL in a healthy subject is about 0-1.3ppm.
- ***Carbon dioxide*** (CO_2) and ***Oxygen*** (O_2): Their quantities show how much O_2 is retained, 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 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

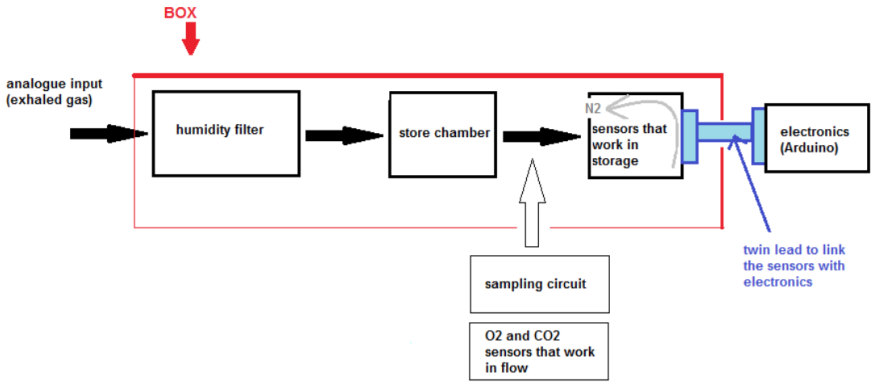

Fig. 1. Schematic sketch of the WS 1.x's architecture

Acquiring Device (AD), a dedicated embedded hardware, including 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 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-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 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.

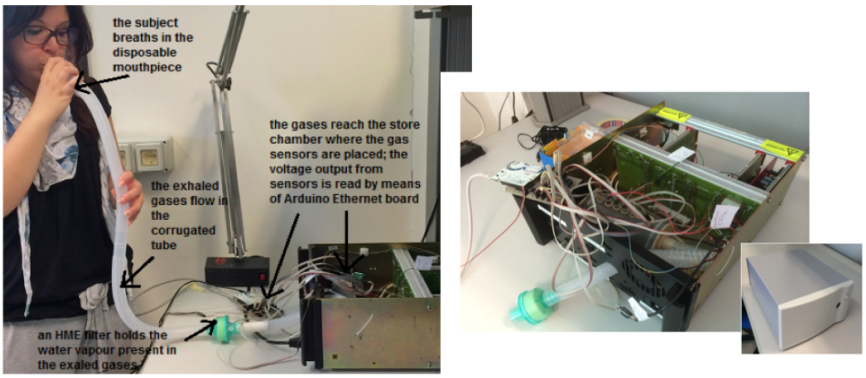

Fig. 2. WS 1.x final set-up

4 Preliminary tests: evaluation of the WS 1.x's performances

A measuring protocol was draft in order to test the Wize Sniffer 1.x on a population of healthy subjects containing individuals of different age, habits, lifestyles, body type. Note that SEMEOTICONS project is focused on the prevention of cardio-metabolic diseases. Consequently, it pays attention not to make a diagnosis, rather than to the monitoring of healthy subjects' well-being, in order to make them avoid the dangerous habits for this type of disease. For our test (conducted following the individuals' habits and lifestyle), 11 non smokers-teetotal/occasionally drinkers ($\leq 2 times/week$), 10 non smokers-moderate drinkers

(3-5 times/week), 7 non smokers- heavy drinkers ($\geq 6 times/week$), 9 light smokers (2-5 cig./day)-teetotal, 5 heavy smokers ($\geq 10 cig/day$)-teetotal, 12 smokers-and-drinkers were chosen. The measuring protocol was draft taking into account

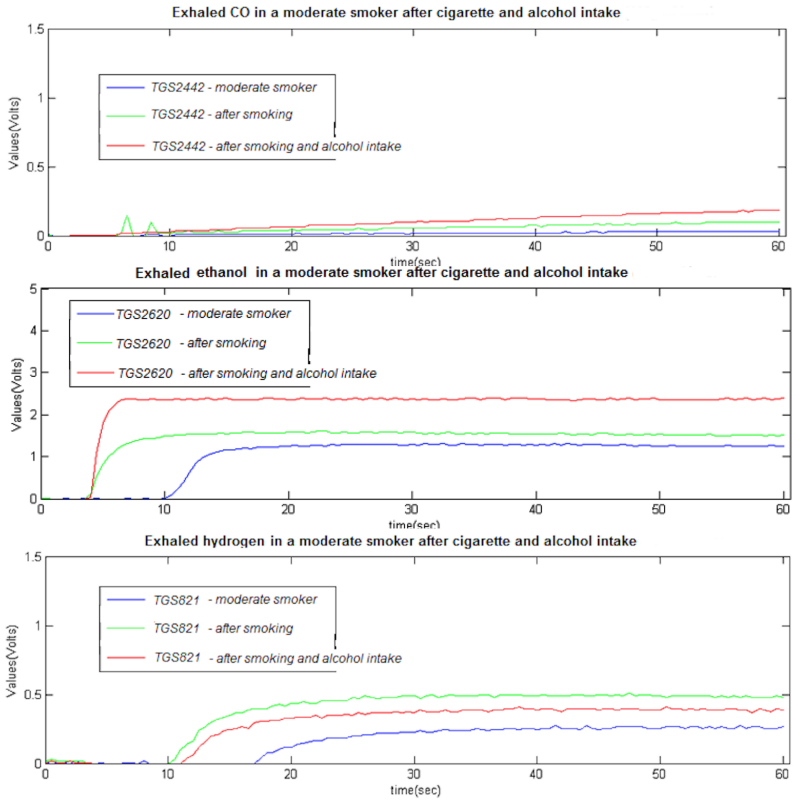

Fig. 3. An outcome of a test. It was carried out on a moderate-smoker, social drinker, healthy subj., female, in the age range (20-29), having normal body type, practicing sport 2 times a week. The subj. breathed before and after smoking, and before and after smoking and drinking alcohol. WS 1.x was able to follow the trend in time of smoking (see exhaled CO detected by TGS2442) and alcohol intake (see exhaled Ethanol detected by TGS2620). Exhaled $H2$ (detected by TGS821) showed an increase after smoking and a decrease after drinking alcohol, in agreement with the literature [5].

also the methodological issues about sampling procedure. In practice are used three methods of sampling: "alveolar (end-tidal) sampling", if only systemic volatile biomarkers are to be assessed, "mixed expiratory air sampling" (which corresponds to a whole breath sample), "time-controlled sampling" (which corresponds to a part of exhaled air sampled after the start of expiration; this method shows large variations of samples compositions because of wide variations of individual breathing manoeuvers). For our purposes, mixed expiratory

air sampling method was chosen, since our interest was focused on endogenous biomarkers, but also to the compounds of exogenous origin. In addition, since the composition of single breaths may vary considerably from each other, because of different modes and depth of breathing, in order to have samples that were as reproducible as possible, we preferred a sampling of multiple (three) breaths.

5 Results and discussion

An example of an outcome of a test is shown in Fig. 3. The typical trends of "exhaled breath curves" 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. 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 of the alcohol intake/disposal. In addition, WS1.x is able to discriminate also between moderate/heavy 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 addition, in order to improve the gas sensors' sensitivity, the development of a new version of the WS based on electrospun nanofibers [7] will be our great future challenge.

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