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Criticality of human breath detection with a portable device III: integration with other devices for health care and self-monitoring

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ABBREVIATIONS AND ACRONYMS

EM	Event Manager
EtOH	Ethanol
GC	Gas Chromatography
HME	Heat and Exchange Moisturizers
IP	Internet Protocol
ISO/OSI	Open System Interconnection/International Organization for Standardization
MAC	Media Access Control
min	minute
ml	milliliter
PC	Personal Computer
Ppm	parts per million
RH	Relative Humidity
s	seconds
SRAM	Static Random Access Memory
TCP	Transmission Control Protocol
USB	Universal Serial Bus
VOC	Volatile Organic Compounds
Vol	Volume
WS	Wize Sniffer
XML	Extended Markup Language
XSD	XML Schema Definition

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1. Introduction

Human breath is largely composed of oxygen, carbon dioxide, water vapor, nitric oxide, and numerous volatile organic compounds (VOCs) [1, 2]. Changes in the concentration of the molecules in VOCs could suggest various diseases or at least changes in the metabolism. Indeed, breath gases are recognized to be excellent indicators of the presence of diseases and clinical conditions. Such gases have been identified as biomarkers using accurate but expensive benchtop instrumentations such as gas chromatography (GC) or electronic nose (e-nose) [1]. As a consequence, in recent years, it has been stimulated the necessity to develop a portable device for breath analysis, easy to use, and feasible for patients living far from medical structures or physicians.

In the framework of SEMEOTICONS (SEMEiotic Oriented Technology for Idividual's CardiOmetabolic risk self-assessmeNt and Self-monitoring) European Project, we developed a low cost, portable, easy-to- use device for the analysis of breath composition: the Wize Sniffer (WS).

The WS captures breath samples, the chemical selective sensors sense the sample and accordingly form a sort of *odor-print* of healthy people or patients with known and specific diseases, in order to evaluate the *well-being* state of a human subject [3, 4]. It should be noted that does not exist a general definition of "well-being state", rather some indices for well-being that can be correlated to cardio-metabolic risk, which is representing the leading cause of worldwide mortality [3, 5].

The breath molecules detected by the Wize Sniffer are the following, all related to those noxious habits for cardio-metabolic risk (alcohol intake, smoking, wrong diet):

- **Carbon Monoxide (CO)**: CO is present in cigarette smoke (it is the major component, 75,95%). Mean carbon monoxide concentration in exhaled breath is about 3,5 ppm. Increasing levels of exhaled carbon monoxide can be detected in smoking subjects: 13.8 - 29 ppm.
- **Carbon Dioxide (CO_2) and Oxygen (O2)**: Exhaled air has a decreased amount of oxygen and an increased amount of CO2. These amounts show how much O2 is retained within the body for use by the cells and how much CO2 is produced as a by-product of cellular metabolism. CO2 is also one of constituents of tobacco smoke (13%). Exhaled O2 amount is about 13.6%-16% while mean CO2 concentration in exhaled breath is about 4% (= 40000ppm). Lower values may be due to respiration disorders.
- **Ethanol**: Exogenous Ethanol comes from alcoholic drink. It is important to note that it is recognized that ethanol breakdown leads to an accumulation of free radicals into the cells, a clear example of oxidative stress. Ethanol may cause arrhythmias and depresses the contractility of cardiac muscle.
- **Nitrogen (di)Oxide (NOx)**: it is a vasodilator and it modulates inflammatory response (operating in combination with CO and Hydrogen Sulfide). It is also a good indicator for asthma diseases.
- **Hydrogen Sulfide (H_2S)**: it is a vascular relaxant agent, and has a therapeutic effect in various cardiovascular diseases (myocardial injury, hypertension). In general, H_2S could have therapeutic effect against oxidative stress due to its capability to neutralize the action of free radicals.
- **Ammonia (NH_3)**: Mean baseline levels of ammonia in exhaled gas are about 0.42ppm. Elevated breath ammonia usually could be due to liver disease, such also to kidney disease. Ammonia is also one of the major compounds, together with CO, of tobacco fumes (approximately 22,15%).
- **Hydrogen (H2)**: The production of hydrogen is a metabolic consequence of carbohydrate fermentation by anaerobic bacteria. This hydrogen traverses the gut wall, and is transported via the circulation to the lungs, where is execrated in exhaled breath. Not only, a certain amount of exhaled hydrogen is the result of fermentation by oropharingeal bacteria. As a consequence, increased values of breath hydrogen may be due to overweight problems, intestinal diseases, improper life-style. The baseline value is about 9.1ppm.

In this report, we describe briefly the hardware/software architecture of the Wize Sniffer, and how it can be integrated in other multisensory platform for health care and self-monitoring.

2. The Wize Sniffer: Hardware and Software Architecture- an Overview

The general scheme of the Wize Sniffer and its final configuration are shown in Figure 1.

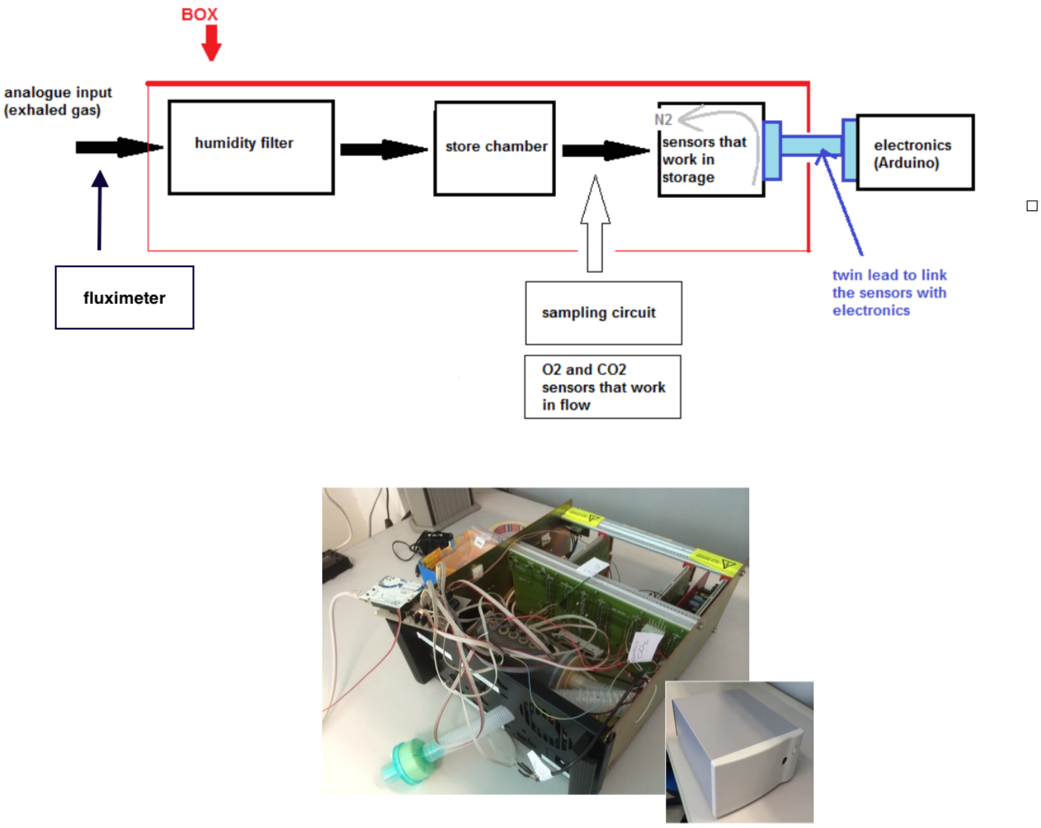

Figure 1. Schematic sketch of the WS system and its final configuration

The WS operates in three phases: gas collection, gas sampling, and data analysis (see Figure 2). It has a store chamber, a HME filter to absorb the water vapor from the breath, and a disposable mouthpiece. The gas sensors placed in the store chamber sense gas particles and generate measurable electronic signals, subsequently sent to the computer for further analysis. Temperature and humidity percentage are measured in situ in the store chamber. A flow-meter allows evaluating the exhaled breath volume. According to the block scheme in Figure 1, the individual breaths in a disposable mouthpiece at the tube's entrance. A heat and exchange moisturizers (HME) filter retains part of the humidity present in human exhaled breath. We provided for a corrugated tube to convey the exhaled gas in the store chamber, made of Delrin and ABS, where six gas sensors are placed. Two uni-directional valves allow the gases to enter the chamber and to be collected within it, preventing the mixing with ambient air. The store chamber's dimension was fixed at about 600ml, according to pulmonary capacity. The store chamber is provided also with a flushing pump which allows to purge the chamber itself, after each measuring. A sampling circuit injects, at a certain rate (=120 ml/sec, basing on [1]), the exhaled gas samples in a second chamber, where two gas sensors provided by COSMED s.r.l. (one sensitive to oxygen manufactured by CityTechnology, the other sensitive to carbon dioxide manufactured by Servomex, both working in flow regime) are placed. To link the gas sensors with other electronics, to send the collected data to Arduino micro controller board, and then to the computer, we thought about a kind of twin lead. An important aspect for the functionality of the WS is that the chamber embedding the sensors could be opened easily, in order to be able to change the sensors, if necessary. All the different steps during the design of the WS were considered at the light of this basic requirement. Box dimensions provided for the WS 1.x family are: 30cm x 38cm x 14cm; its weight is 9 Kg. The device requires a voltage supply of 12V.

2.1 THE COMMERCIAL GAS SENSORS

The choice of gas sensors has been made taking into account the breath compounds to detect and the working principle of the sensors. The aim of WS is to detect those compounds, present in human exhaled gas, correlated to cardio-metabolic risk. As a consequence, our interest, during a first phase of the work, was focused on: oxygen, carbon dioxide, carbon monoxide, ammonia, hydrogen, hydrocarbons, ethanol, hydrogen sulfide, also according to the suggestions by SEMEOTICONS' physicians.
Criteria for choosing sensors' working principle, was based on their ease of use. So, we selected metal oxide semiconductor gas sensors. Their functioning is based on a variation of resistance from R_0 to Rs when the sensor senses the gas particles. An analogue voltage is measured as indirect measure of change in resistance. Furthermore, basing on the study of Guo et al. [1], we chose chemical gas sensors manufactured by Figaro Engineering, because such kind of sensors are very robust, sensitive, resistant to humidity and ageing. We selected the following 6 gas sensors:

- **TGS 2602**: sensitive to hydrogen, ammonia, ethanol, hydrogen sulfide, toluene, cigarette smoke;
- **TGS 2620**: sensitive to hydrogen, carbon monoxide, ethanol, methane, isobutane;
- **TGS 4161 and its module AM-4-4161**: sensitive to carbon dioxide;
- **TGS 2442**: sensitive to carbon monoxide;
- **TGS 2444**: sensitive to ammonia;
- **TGS 821**: sensitive to hydrogen.

The sensitivity characteristic of each sensor varies according to humidity percentage present in the chamber or, generally, in the environment where the sensors are placed. For this purpose, a temperature and humidity sensor, Sensirion SHT11 was integrated into the store chamber. Sensirion SHT11 has a humidity accuracy of about +/-3.5% and a temperature accuracy of about +/-0.5°C@25°C. It has a digital output, in contrast to other sensors (the gas ones) which have an analogue output.
Two additional sensors, MOX20 sensitive to **oxygen and** manufactured by CityTechnology, IR1507 sensitive to **carbon dioxide and** manufactured by Servomex, were inserted in our device. These sensors work in *flowing-regime*: they sense gases' stream that is injected at a constant rate (120ml/s) by the sampling pump. This electro-mechanic pump takes gas samples from the store chamber, injects them where the O2 and CO2 sensors are placed. Then, gases are brought back to store chamber.
Here, a table that summarizes the commercial sensors used for WS 1.0 and WS 1.1 and the molecules to be detected (Table 1).

Table 1. Sensors, detected molecules and optimal detection range.

SENSOR	DETECTED MOLECULE(S) / PHYSICAL QUANTITY	OPTIMAL DETECTION RANGE
FIGARO TGS2602	hydrogen, ammonia, ethanol, hydrogen sulfide	1-10 ppm
FIGARO TGS821	hydrogen	1-1000 ppm
FIGARO TGS2620	hydrogen, carbon monoxide, ethanol	50-5000 ppm
FIGARO TGS2442	ammonia	10-1000ppm
FIGARO TGS2444	carbon monoxide	10-100ppm
FIGARO TGS4161	carbon dioxide	350-10000ppm
Servomex IR1507	carbon dioxide	0%-5%
MOX20 CityTechnology	oxygen	20.93%+/-10%
SENSIRION SHT11	temperature and humidity	-40°C-123°C 0%-100%

2.5 The circuit and Arduino board

In order to receive the data from the sensors, we decided to make use of a microcontroller board, an Arduino board. Initially, the choice of the type of Arduino board has been made taking into account:

- Number of bits of analogue-to-digital converter;
- Number of analogue input pins;
- SRAM at least of 8KByte.
- Possibility to use an Ethernet module;

This last requirement was due to the advantage of sending the data from Arduino to computer wireless. Our aim was to create a Telnet server by using Arduino, in order to read data by making a simple request to the server itself from our computer.
On the basis of these requirements, we used Arduino Mega 2560 with an Ethernet module.

2.6 The communication protocol between Arduino and PC

Before integrating the Wize Sniffer into the Wize Mirror, we tested its functionality and its performances using a laptop. These tests were needed also to try the communication protocol between the WS and another platform, in this case, the PC.
The section 5 will be dedicated to the communication protocol between Arduino and the main board of the Wize Mirror.
Usually, when Arduino board is used to read data from sensors, or from other devices, a USB cable is the simplest way to link a personal computer with Arduino itself. Nevertheless, this is not very advantageous if the computer is placed far away from Arduino. A wireless connection between the devices becomes necessary. The idea we had can be explained as in Figure 2.
First, we programmed Arduino in order to create a Telnet Server and to read the sensors' output data. Subsequently, to send a request to this Telnet Server, and receive data from it, we created a TCP/IP object implemented on Matlab®. It allows to make a connection to server's port 23 and fill the buffer (which dimensions can be set) with the data coming from the server. It means, the buffer is filled with the sensors' values array.
Moreover, the data received can be saved in a text file in order to be managed for further analysis.

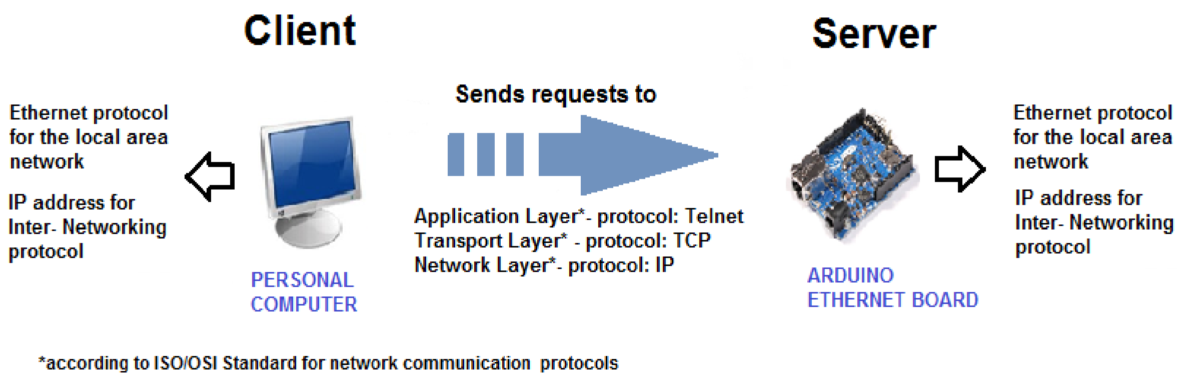

Figure 2- Schematic of the communication protocol.

3. How the Wize Sniffer can be integrated into another multisensory platform for home care and self- monitoring.

As we describe in the previous sections, the WS solution in based on an internal two-way architecture. The two systems which form the WS are an Arduino and a Sensors System. The Arduino works as request manager, sensor's control and answer manager. In detail, Arduino is an open-source physical computing platform based on a simple I/O board and a development environment that implements the Processing/Wiring language.

Here we simulate the integration of the Wize Sniffer into another multisensory platform whose aim is to monitor the user's well-being state (exactly as the Wize Sniffer).

We suppose a sort of main board, which we can call "Event Manager" (EM), into the multisensory platform, which coordinates the activities of all the sensors and the device included in the multisensory platform itself. Then, we can suppose that the EM manages also our Wize Sniffer's processes. Figure 3 summarizes the described such scenario.

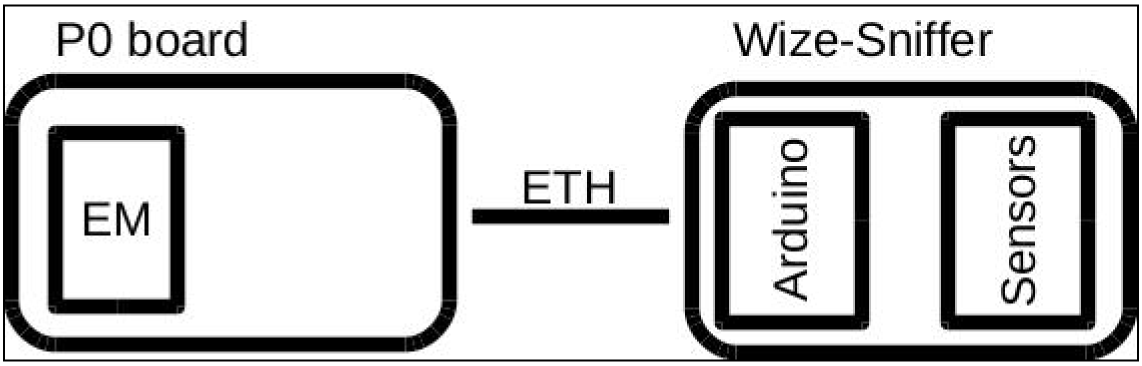

Figure 3- The connection between the EM module and Arduino

The messages exchanged between EM and WS (connected each other via Ethernet as in Figure 3) may refer to the following XSD schema:

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<xs:schema version="1.0" xmlns:xs="http://www.w3.org/2001/XMLSchema">

<xs:complexType name="SEMEOTICONSCommunication">
<xs:sequence>
<xs:element name="P4Request" type="P4Request" minOccurs="0"/>
<xs:element name="P4Response" type="P4Response" minOccurs="0"/>
</xs:sequence>
</xs:complexType>

<xs:complexType name="P4Request">
<xs:sequence>
<xs:element name="userid" type="xs:int"/>
</xs:sequence>
</xs:complexType>

<xs:complexType name="P4Response">
<xs:sequence>
<xs:element name="sensor_ready" type="xs:boolean"/>
<xs:element name="userid" type="xs:int"/>
```

```
<xs:element name="examination" type="examination" minOccurs="0"/>
</xs:sequence>
</xs:complexType>

<xs:complexType name="examination">
<xs:sequence>
<xs:element name="validExamination" type="xs:boolean"/>
<xs:element name="measures" type="measures" minOccurs="0"/>
</xs:sequence>
</xs:complexType>

<xs:complexType name="measures">
<xs:sequence>
<xs:element name="v1" type="xs:double"/>
<xs:element name="v2" type="xs:double"/>
<xs:element name="v3" type="xs:double"/>
<xs:element name="v4" type="xs:double"/>
<xs:element name="v5" type="xs:double"/>
<xs:element name="v6" type="xs:double"/>
<xs:element name="v7" type="xs:double"/>
<xs:element name="temperature" type="xs:double"/>
<xs:element name="humidity" type="xs:double"/>
</xs:sequence>
</xs:complexType>
</xs:schema>
```

A typical incoming message (from WS to EM) may be:


```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?><ns2:SEMEOTICONSCommunication
xmlns:ns2="SEMEOTICONSCommunication"><P4Request><userid>007</userid></P4Request></ns2:SEME
OTICONSCommunication>
```


Unfortunately, the lack of memory and computational capability (well balanced by the low energy consuming) could not permit to implement a real XML parser, so Arduino could be programmed to recognize the number of the user (delimitated by user-id tag) and the end of the message. Moreover, it could receive only a request to start a new analysis.
The XML is based on a finite state automation that reads the input of message char by char. The finite state automation implements a parser that reads six characters to identify a token.

Moreover, Arduino collects the flowmeter values in order to measure the exhaled volume. If the exhaled volume of the user is not enough to perform the measure, the measure is aborted. On the contrary, Arduino continues with sensor reading.
When a measure is completed, Arduino may provide the result and write an answer according to the presented XSD Schema. An instance of answer follows:


```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?><ns2:SEMEOTICONSCommunication
xmlns:ns2="SEMEOTICONSCommunication"><P4Response><userid>007</userid><examination><validExa
mination>true</validExamination><measures><V1>1.11000</V1><V2>2.22000</V2><V3>3.33000</V3><V
4>4.44000</V4><V5>5.55000</V5><V6>6.66000</V6><V7>7.77000</V7><temperature>8.88000</temper
ature><humidity>9.99000</humidity></measures><Class>NC</Class></examination></P4Response></ns2
:SEMEOTICONSCommunication>
```

Nevertheless, some communication problems can be foreseen. Usually, an EM uses readUTF class to read socket messages (the messages sent by Ethernet) which is not compatible with Arduino library; moreover, Arduino and Java machine use different endian data representation.
In order to solve such problem the WS architecture may be changed by inserting a middleware able to link EM and Arduino. This introduces a *three-way* architecture, like the one shown in Figure 4.

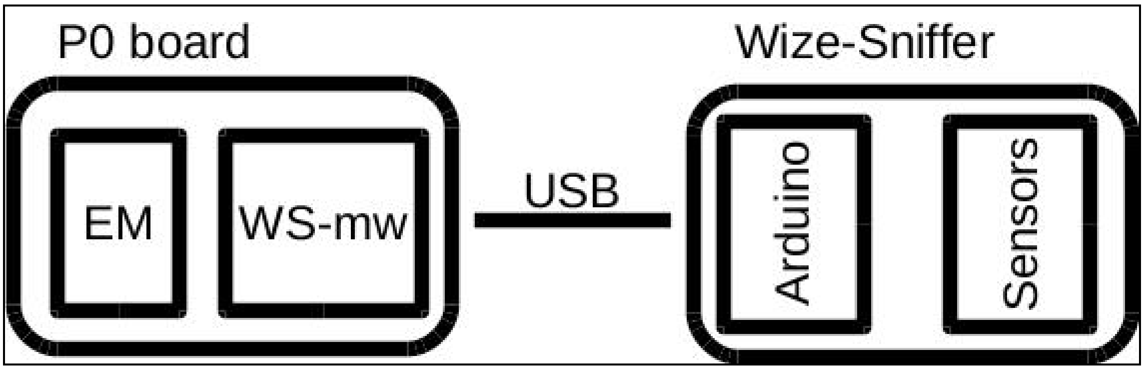

Figure 4. The connection between the EM module and Arduino using a middleware

Arduino external channel changes from Ethernet to USB and the WS-middleware uses Java.
The middleware simply reads from Ethernet a message and send the message to Arduino using the USB port, waits for Arduino response and sends back the answer to the caller. In order to efficiently manage the communication the WS-middleware may be written using concurrency criterion: it is composed by 4 threads that exchanges internally the messages and are suspended when their own task is finished.

4. CONCLUSIONS

In this report, we have briefly described the final hardware/software architecture of the Wize Sniffer, an innovative device able to operate with a limited number of breath VOCs, principally related to those noxious habits for cardio-metabolic risk (alcohol intake, smoking), thus giving information to physicians on the possible state of wellness of an individual.

The results obtained give us the opportunity to have a final hardware/software configuration of the Wize Sniffer as considered as a standalone device.

Not only, being based on a modular, low cost, wide employed technology, the Wize Sniffer can be integrated very easily also in other multisensory platforms, as we described in this report.

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