SEMEOTICONS – READING THE FACE CODE OF CARDIO-METABOLIC RISK

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ABSTRACT

What if you could discover your health status by looking at yourself in the mirror? Since November 2013, the EU FP7 Project SEMEOTICONS is working to make this possible. The Project is building a multi-sensory device, having the form of a conventional mirror, able to read the semeiotic code of the face and detect possible evidence of the onset of cardio-metabolic diseases. The device, called *Wize Mirror*, integrates unobtrusive imaging sensors used to capture videos, images and 3D scans of the face. These are processed to assess the risk of a cardio-metabolic disease and thereby suggest possible strategies to prevent its onset.

***Index Terms*—** 3D shape analysis, Face tracking, Face semeiotics, Quantified Self, Personal Informatics

1. INTRODUCTION

Discovering your health status by looking at your image in the mirror: this is the main goal of the EU FP7 Project SEMEOTICONS - SEMEiotic Oriented Technology for Individual's CardiOmetabolic risk self-assessmeNt and Selfmonitoring (http://www.semeoticons.eu). Since November 2013, SEMEOTICONS Consortium is working to define the digital semeiotics of the face, i.e. the computerized evaluation of facial signs, to detect health deteriorations through the analysis of one's face appearance over time. The Project is developing a multisensory device, having the form of a conventional mirror, which integrates optical, depth and gas sensors. The device, called WizeMirror (see Fig. 1), processes the heterogeneous sensor data to look for signs that indicate an increase in the risk of cardio-metabolic diseases (i.e., cardiovascular diseases or type-2 diabetes), which are among the leading causes of death and disabilities worldwide.

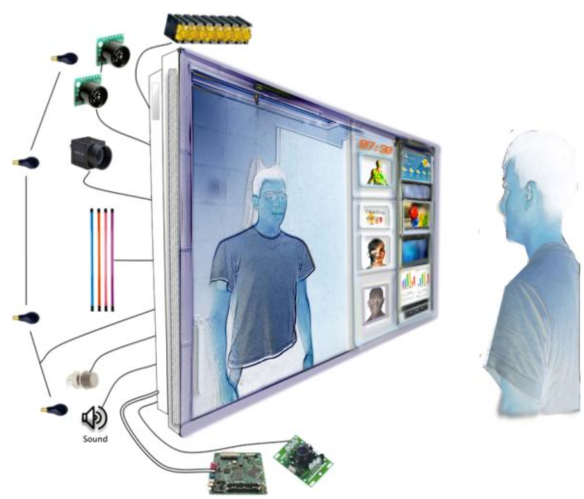

Figure 1. *A sketch of the Wize Mirror*

Face modeling and characterization over time, in 2D and 3D space, are fundamental premises to engineer the face semeiotic code. They yield the shift from images and videos to computational descriptors of face shape and appearance, face skin composition and function. In this paper, we briefly present SEMEOTICONS, by starting from the medical concepts that set the foundations of the Project. We overview the main research activities relying on face modeling, and complete the picture by explaining how face signs will be interpreted.

2. THE FACE SEMEIOTICS OF CARDIO-METABOLIC RISK

The appearance of human face conveys vibrant information about the healthy or unhealthy status of individuals. It is at the basis of medical semeiotic analyses, which look at the face to obtain evidences on one's nutrition, fitness, and mental state. The face signs usually considered are the color of the skin and mucous, the distribution of subcutaneous fat, the structure of fleshy and bony zones, the perspiration pattern, and the facial gesture and expressions. The observation of these signs remains an important part of the physical examination, and, together with the anamnesis, constitutes the basis for a rational decision-making. In this respect, face semiotics provides surrogate markers for the assessment of the cardio-metabolic syndrome: a generalized disorder resulting from metabolic abnormalities that increases the risk of cardiovascular diseases and type-2 diabetes [1].

The main modifiable risk factors at the basis of the syndrome produce some visible manifestations that can be observed by looking at the face appearance. Some of them may require going beyond the physiognomic manifestations and look into skin tissue composition and function or obtain additional data such as physiological parameters (e.g., heart rate) or the composition of the breath. More precisely, the main risk factors and their manifestations can be listed as follows:

- overweight and obesity: weight gain produces characteristic changes that results in fatty physiognomies easily detectable;
- in hyper-cholesterolemia, the skin depot of cholesterol increases (usually,
- hyper-cholesterolemia: when blood cholesterol is high, the skin depot of cholesterol increases as well, and, when very high, it may result in focal accumulation in the eyelid (i.e., the so-called xantelasmas) and in the cornea (i.e., the so-called arcus cornealis);
- hyper-glycaemia: the metabolic alterations that characterize hyper-glycaemia and diabetes produce the accumulation of Advanced Glycation End-products (AGE) in the skin [2];
- cardiovascual homeostasis impairment: skin microcirculation (i.e., endothelial function) is an important indicator of homeostasis and can be appreciated on the skin after local heating [3]. Also heart rate variability can be an informative sign of the functioning of the autonomic nervous system that regulates homeostasis [4];
- unfavorable psychological conditions: recurring states of distress, fatigue and anxiety produce visible expressive signs, such as wrinkles or eye circles, and result in peculiar face gestures;
- noxious habits: smoking and alcohol abuse, can produce subtle signs on skin color and appearance. More significantly, they result in the accumulation of specific substances in the exhaled air.

By putting together the face alterations produced by the above mentioned risk factors and tracking their evolution over time, it can be possible to promptly identify the onset of the cardio-metabolic syndrome and act to reduce its development.

These factors are mainly modifiable and related to lifestyle choices. In this respect, primary prevention, in terms of healthy lifestyle, is really the best strategy to counteract the cardio-metabolic syndrome.

SEMEOTICONS aims at foster primary prevention through a non-diagnostic personal device. Next sections provide the reader with a technical overview of the Project activities in this respect.

3. SEMEOTICONS OVERVIEW

We are working to define a *semeiotic model* of the face for cardio-metabolic risk. We are including all the signs potentially caused by the main risk factors. These are detected by capturing images and videos of the face as well as breathe air signals.

The Wize Mirror seamlessly integrates depth sensors and an infrared camera used to realize a cheap 3D scanner. A multi-camera system, consisting of five cameras, mimics a multispectral system needed for an insight into invisible features of face skin. An ad-hoc gas sensor, called *Wize Sniffer*, is also included for exhaled air analysis. This suite of sensors remotely collects heterogeneous data of the person in front of the mirror. The data are processed to extract computational descriptors of face signs. The set of descriptors includes:

- 3D morphological face descriptors, related to overweight, obesity, swelling, and asymmetry, computed on a reconstructed 3D face model;
- facial descriptors revealing stress, fatigue and anxiety, captured via 3D and 2D expression analysis on video sequences, and skin face colorimetric descriptors, such as pallor, redness, jaundice;
- physiological parameters such as heart rate, heart rate variability, and respiratory rate, all estimated from videos by detecting face color changes and cyclic movements actions;
- descriptors of face skin composition and function associated with diabetes, cholesterol, and endothelial dysfunction, evaluated through the multi-camera system;
- concentration of volatile substances present in the exhaled gas, measured by the Wize Sniffer, which gives feedback about noxious habits such as smoke and alcohol intake.

The descriptors are to be integrated to define a *Virtual Individual Model* of the person, and to estimate an individual *Wellness Index*. The daily values of such an index are recorded in a health diary and shown through a user-friendly graphical interface on the Mirror. In accordance with the evolution of the wellness index, the system will provide a personalized user's guidance so as to give useful suggestions and information on correct lifestyle, as a personal trainer will do. Tracking the evolution in time of their Wellness Index will enable common people to self-assess and self-monitor their well-being status over time. This, coupled with the personalized user guidance, is meant to lead towards the achievement and the maintenance of a correct lifestyle.

In the following, we overview the main goals and tasks of face characterization (Section 3.1) and how face signs are wrapped up into an overall picture of the subject in front of the Wize Mirror (Section 3.2).

3.1. Face characterization

Extracting the computational descriptors relies on suitably modelling the face in the 2D and 3D space. The Wize Mirror works to (*i*) detect and track in the 3D space the head of the person in front of the Mirror (*ii*) reconstruct a 3D model of the face, (*iii*) characterize 3D face shape and appearance, (*iv*) analyze emotional states and additional physiological parameters, (*vi*) assess the composition and function of skin levels. In the paragraphs below, we report the main peculiarities and the results achieved so far for each of these functionalities.

3.1.1. Face detection and tracking

Enabling the unobtrusive acquisition of sensor data requires to automatically detect the person in front of the Mirror and track the pose of her head in 3D. This allows for localizing the person and figuring out if the position of the head is suitable to proceed with the extraction of the computational descriptors. The main challenge in this respect is the necessity to use an inexpensive 3D scanner consisting of range sensors and an infrared camera.

The work on this issue finished obtaining very good results with a method based on a random forest framework, used to classify depth image patches between two different classes (head and no head) [5]. Such a method uses a personalized 3D mask to improve the spatial accuracy of face detection (see Fig. 2).

Figure 2. *Face detection and recognition with the personalized mask.*

3.1.3. 3D face reconstruction

The 3D face reconstruction is functional to the extraction of morphological descriptors.

Range sensor images are used to this end. Currently we are working on an approach based on the method reported in [6], by considering that the sensor is in a fixed position and the subject is moving. The output is provided as a triangulated 3D point cloud. A sample of the preliminary results is shown in Fig. 3.

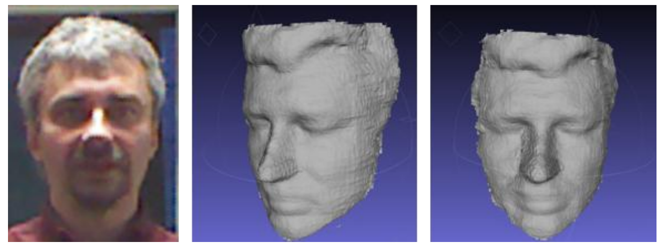

Figure 3. *A sample 3D face reconstruction.*

3.1.2. 3D face shape and appearance

3D face data are analyzed to monitor and quantify temporal facial variation related to fat accumulation. This usually produces an increase in some facial dimensions, as observed for example in a study about the face morphology of obese adolescents [7]. Other studies demonstrated that some geometrical facial features in the 2D space are strictly related to Body Mass Index and Waist Circumference [8]. In SEMEOTICONS, we are testing Persistent Homology on different configuration of soft-tissue face landmarks. The method gets in input the 3D Delaunay triangulation, whose nodes correspond to anthropometric landmarks and edge lengths to their Euclidean or geodesic distances, and returns as output the shape descriptor (a persistence diagram) giving information on the geometry and topology of the landmark structure. Due to a lack of longitudinal studies on real subjects, a dataset of synthetic 3D faces simulating weight changes was generated using a parametric morphable model [9] and used for the first experiments. Fig. 4 shows a face in the dataset and two of its deformations, with the anthropometric landmark configuration superimposed.

Figure 4. *Facial landmarks on a synthetic individual fattening (three stages of face fattening).*

3.1.3. Emotional state and physiological parameters.
To detect adverse psychological states such as fatigue, stress and anxiety, several gestural and physiological signs are detected and monitored. According to the literature, the relevant gesture is mainly related to eyes, eyebrows and mouth movements (e.g., pupil dilation, blink rate, yawning). This is detected by processing high resolution images captured at high frame rate. Several algorithms are under development and stem from face detection, tracking and segmentation of appropriate regions of interest described above to apply different techniques for motions pattern analysis [10]. Testing is currently performed on synthetic and real data. Additional methods are under development to detect physiological parameters such as heart rate, heart rate variability and respiratory rate by analyzing face color variations in high frequency images.

3.1.4. Composition and function of skin levels
The multispectral imaging of facial skin aims at determining endothelial function, cholesterol concentration, and AGE accumulation in specific regions of interests of the face [11]. The principle for measuring endothelial function is to evaluate skin hyperemia during local heating. Skin cholesterol determination is based on characterization of spectral features during controlled illumination. The AGE accumulation is measured using UV induced auto-fluorescence. The idea of analyzing skin composition and function remotely is a completely innovative approach, which is recording promising results.

The multi-camera system comprises compact cameras with filters at selected wavelengths controlled by a computer. It consists of five small monochrome 3.2 MP USB 3.0 CMOS cameras, computer controllable light sources (a bright white-LED and UV-LED, respectively), and a remote skin heater.

3.2. The overall picture

All the computational descriptors obtained from face characterization are integrated to build a *Virtual Individual Model* (VIM) of the subject analyzed. The VIM also comprises the results of the breath composition analysis. This is carried out by the Wize Sniffer which is a portable, cheap, and easy-to-use device able to analyze breath gases in real time. It captures breath samples, and, thanks to a chemical gas sensors array, detects a selected number of molecules (i.e., carbon dioxide, oxygen, hydrogen, ethanol, carbon monoxide, ammonia). Such molecules are those related to cardio-metabolic risk, or to noxious habits [12].

The VIM defines a wellbeing space where each individual is tracked overtime. The baseline localization in this space is based on information pertaining to one's health behaviors and clinical risk factors. The *Wellness Index* (WI) derived from the VIM is a non-diagnostic estimation useful for self-assessment and self-monitoring. The index is based on both subjective criteria (e.g., perceived physical and mental status recorded via properly selected questionnaires) and objective data, i.e. the parameters measured on the sensed data described in the previous section. To validate the results of the WI estimation, well-established cardio-metabolic risk charts (e.g., HEART SCORE, Fatty-Liver index, HOMA index, FINRISK index) are being taken as ground-truth [1]. The Wize Mirror is meant to provide customized and personalized suggestions and messages, in accordance with the estimated WI and its variation over time. To promote health education, ad hoc information and educational messages will be provided to users. The messages are to be tailored to users' characteristics so as to increase information intake and user engagement.

The presentation, visualization and linguistic style of suggestions are studied to be in accordance with users' peculiarities, since they are important moderators in communication modalities.

4. DISCUSSION AND CONCLUSION

It is a matter of time that specific hardware platforms with high performances, low-cost and low power consumption will replace conventional PCs for novel applications like the one developed in SEMEOTICONS. A user-centric approach is at the basis of the Wize Mirror which will support the users in self-assessing the quality of their lifestyle and self-monitoring their psycho-physical status over time. The Wize Mirror will straightforwardly fit normal life settings and might be easily integrated, as a piece of house ware, at home, or at different levels of the health care delivery chain, including fitness centers, nutritional centers, pharmacies, and so on. The Wize Mirror will help people to detect unhealthy behaviors connected to diet, psychophysical stress conditions, physical inactivity and sedentary lifestyle. At the same time, the Wize Mirror will offer a natural interface between the users and their body, and strengthen the users' awareness about personal wellbeing. This empowerment of individuals to improve and manage personal life conditions is a strategic challenge in current policies for preventing cardiovascular diseases. Indeed, proper adaptation of personal lifestyle allows influencing most modifiable cardio-metabolic risk factors

Currently, we have developed a first prototype of the Wize Mirror, to define a final setup of sensor arrangement and user interactions. A final prototype will be released by the end of next April and tested in three clinical centers in Italy and France. The Wize Mirror will be the first example of a piece of house-ware made intelligent and able to put common people in the center of their health care.

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