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Face morphology: Can it tell us something about body weight and fat?

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ABSTRACT

This paper proposes a method for an automatic extraction of geometric features, related to weight parameters, from 3D facial data acquired with low-cost depth scanners. The novelty of the method relies both on the processing of the 3D facial data and on the definition of the geometric features which are conceptually simple, robust against noise and pose estimation errors, computationally efficient, invariant with respect to rotation, translation, and scale changes. Experimental results show that these measurements are highly correlated with weight, BMI, and neck circumference, and well correlated with waist and hip circumference, which are markers of central obesity.

Therefore the proposed method strongly supports the development of interactive, non obtrusive systems able to provide a support for the detection of weight-related problems.

1. Introduction

Overweight and obesity (defined as abnormal or excessive fat accumulation) represent a major risk factor for a large spectrum of diseases, including cardiovascular disease, diabetes [1,2], musculoskeletal disorders, and some cancers (endometrial, breast, and colon). Data published by the Global Health Observatory in [3] show that excess body fat affects a large part of the adult population (aged 18 and over): around 39% were overweight in 2014 and 36.1% in 2010; while obese adult people were 13% in 2014, and 11.3% in 2010. Hence, overweight and obesity are increasing, and cause direct and indirect costs, stressing healthcare and social resources: strong actions to prevent unhealthy behaviours in the general population are mandatory.

In recent years, personal health monitoring systems are gaining popularity, since individuals are increasingly more motivated to play an active role and are shifting from passive recipients of care towards actively managing their own health [4]. The SEMEOTICONS project (described also in [5,6]) falls in this domain: it aims to build a sensorized platform, the *Wize Mirror*, able to track over time the individual health status, and offer a tailored guidance towards lifestyle improvements, as described in [7,6]. Such a mirror arises from the integration of different modules, processing different data, which are acquired unobtrusively. In this paper, the advances in 3D scanning technologies and 3D geometry analysis are exploited to develop a method for the automatic and reliable estimation of weight-related health parameters, as a key component of easy-to-use, low-cost yet accurate healthcare tools. In the Wize Mirror, the estimation of such parameters will be complemented with results from the analysis of skin composition, emotional status, heart rate, endothelial functionality, chemical composition of the exhaled, in order to draw an overall picture of the individual's wellbeing status with respect to the cardio-metabolic risk.

The peculiar focus of this work is on the ability of digital measurements on 3D face scans to enclose the information about body weight and fat, which is measured in literature through well established indicators, such as weight, Body Mass Index (BMI), waist circumference, hip circumference and neck circumference. We focus on the *face*, following the principles of *medical semeiotics*, which considers the face as a mirror of wellbeing [8–10]. The challenge is significant: though it is well known that the face is involved in the process of fat accumulation, there is no consensus in the literature about which are the facial morphological correlates of body weight and related indexes (Section 2.2).

The contribution of this work is three-fold, on both the technological and the clinical side:

- We propose a low-cost, yet accurate, 3D face reconstruction system (Section 3.1); this makes the proposed method a viable

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solution in everyday scenarios, including home, pharmacies, and schools.

- We define a set of automatic digital face measurements based on modern 3D shape analysis techniques (Section 3.2), which can be accurately computed without requiring any manual intervention.
- We show evidence of the correlation of the proposed facial measurements with standard parameters of overweight and obesity (including weight, BMI, waist circumference, hip circumference, neck circumference, and fat mass) in a study on 30 volunteers (Section 4); this evidence may support the adoption of the proposed measurements in self-monitoring applications for wellbeing.

2. State of the art

Anthropometry is the discipline which deals with the study of body and face morphology: it has been used for decades to measure individuals and quantify human physical variation through measurements performed manually by trained personnel with results often affected by inter- and intra-observer variability. Section 2.1 reports on the most common parameters to estimate the size and composition of the human body, and also to assess overweight and obesity.

Recently, the development of 3D scanning technologies opened a new field of research named *digital anthropometry*. The accuracy of digital measurements has been shown compatible with applications in forensic medicine, ergonomics, clothing industry, and medical settings [11,12]. In Section 2.2, we report on existing computational measures related to overweight, obesity and cardio-metabolic risk.

2.1. Standard anthropometric measurements

Anthropometry, in the medical domain, refers to a set of simple, inexpensive and non-invasive methods to understand the physical properties of the human body and face, such as size and shape. Also, measurements and indexes derived from anthropometry may be used to monitor the nutritional status, and are currently studied to disclose existing relations with syndromes, as the obstructive sleep apnoea, reported by Balabilh et al. in [13]), and health risk factors, such as the cardiovascular or the cardio-metabolic risk, in [14] by Millar et al.

The first indicator of generalized obesity, probably the most used and debated, is the body mass index (BMI), introduced in [15]. BMI is computed using only weight and height [BMI = (weight in kilograms)/(height in metres)^2]; although simple, it shows a high correlation (0.7–0.8) with body fat in the adult general population, as reported in [16,17]. Hence, BMI is still used for statistical surveys of large population. Nonetheless its cut-off values are the same for male and female subjects, for all ages in the adult population (18 years and over). On the contrary, it is a crude measure, not distinguishing lean mass from fat. Scholars continue working on new measures and indexes, superior to BMI for the prediction of the overall health status.

Among the measures proposed to predict the cardio-metabolic risk we mention the following:

- the waist circumference (WC), a relatively simple and convenient measure to detect central fat accumulation [18–20];
- the hip circumference (HC), which provides additional information about the hip region, negatively associated with health outcomes in women [21];
- the waist-to-hip ratio (WHR), as it indicates increased cardiovascular risk [22];
- the neck circumference (NC), being a marker of central obesity, and associated with many fat-related anthropometric measurements and cardiovascular risk factor [23–25].

In the present study weight, BMI, WC, HC, and NC are considered as reference anthropometric measurements against which to validate the digital face measurements defined in Section 3.2.

2.2. Digital anthropometric measurements

State-of-the-art shape analysis provides a rich and powerful set of tools which automatically extract information from a 3D object (see [26] for a recent review). Computer vision and computer graphics have been applied to body analysis to estimate height, weight and other parameters enclosed in the body appearance.

Velardo and Dugelay presented a regression model for the weight estimation based on a set of geometric body measurements extracted from the 2D body silhouette [27]. They also propose in [28] an automatic vision-based system for estimating the subjects' absolute weight from a frontal 3D view of the user, acquired through a low-cost depth sensor; example of applications of such a system are extreme environments and circumstances in which a standard scale cannot work or cannot be used.

Giachetti et al. [29] used heterogeneous body scans as input data for the automatic extraction of geometrical parameters related to body fat. Their aim was the computation of parameters not dependent on the precise location of anatomical landmarks, and robust against pose and mesh quality, so as to be used in healthcare applications. They found that several parameters were highly correlated with total-body-less-head fat and trunk fat (computed via Dual-Energy X-rays Absorptiometry scanning).

As far as faces are concerned, most of the methods proposed in the literature are based on 2D images. Moreover, no conclusive results can be drawn about the morphological facial correlates of body fat. In [30] Ferrario et al. observed an increase in some facial dimensions in a study on the face morphology of obese adolescents. Djordjevic et al. in [31] reported an analysis of facial morphology of a large population of adolescents under the influence of confounding variables: though the statistical univariate analysis showed that four principal face components (face height, asymmetry of the nasal tip and columella basis, asymmetry of the nasal bridge, depth of the upper eyelids) correlated with insulin levels, the regression coefficients were weak, and no significance persisted in the multivariate analysis.

Only very few methods exploit 3D information: one of the most interesting is presented by Banabilh et al. in [13]), in which the craniofacial obesity, assessed via 3D stereo-photogrammetry, is correlated with the obstructive sleep apnoea syndrome.

In adults, Lee et al. proposed in [32] a prediction method of normal and overweight females based on BMI using geometrical facial features only. The features, measured on 2D images, include Euclidean distances, angles and face areas defined by selected soft-tissue landmarks. The study was extended and completed in [33] by investigating the association of visceral obesity with facial characteristics, so as to determine the best predictor of normal waist and visceral obesity among the considered facial characteristics. Cross-sectional data were obtained from a population of over 11 thousand adult Korean men and women aged between 18 and 80 years. Also, in [34] Giorgi et al. defined a more complex shape descriptor from the geometric theory of persistent homology, to analyse the face morphology encoded in a set of 23 landmarks (a subset of the facial Farkas landmarks, defined in [35]), and tested it on a synthetic dataset of 3D faces.

The present study differs from the state of the art in some aspects: the method proposed for the self-assessment of the wellbeing status with respect to the cardio-metabolic risk is fully