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Machine Learning Opportunities for Automatic Tongue Diagnosis Systems

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***Abstract*—Machine Learning approaches and the availability of digital data are favoring the rising of applications in biomedical field. Smartphones and wearable devices are facilitating the acquisition of images and audio files of the population and this is fueling patient-centric approaches as regards to the diagnosis of specific diseases. This trend is desired by the World Health Organization both for a view to monitoring and empowering the population and for encouraging the containment of medical costs. Tongue inspection is a clinical practice of Traditional Chinese Medicine (TCM) that has been existing for thousands of years, and allows to intercept diseases and severity of internal organs. While in the past, the traditional diagnosis of the tongue depended on the observation of the doctor, now the use of automatic computerized diagnosis systems is conceivable. In this paper, we focus on the topics of interest from which to start to prototype mobile solutions for tongue diagnosis based on artificial intelligence.**

***Index Terms*—Tongue Imaging Analysis, Automatic Tongue Diagnosis System, Machine Learning on Tongue Analysis**

I. Introduction

In the millennial Traditional Chinese Medicine (TCM), classical clinical examination includes inquiry, inspection, auscultation, olfaction, and palpation. Based on the data collected by these diagnostic methods, several diseases can be revealed. In particular, tongue analysis is greatly taken into account and is used as an extraordinary diagnostic method for which it has been proved that correlations exist between the aspect of the tongue and the patient's health status.

Tongue analysis has not the insignificant advantage of deriving from a non-invasive observation while allowing to understand the pathological changes of the body. According to the fundamental principles of reflexology, in fact, "part reflects the whole" and "abnormal external manifestations are the reflection of diseases of the internal organs" [1]. Therefore, any observable anomalies on the tongue could be indicative of pathologies both of internal organs and related to psychosomatic disorders.

Under normal conditions the tongue should be flexible, with the body slightly moist and light red with the presence of a possible thin white coating. TCM doctors observe changes in color, shape, fissure, red dot, ecchymosis, moisture in the tongue coating and body color as indicative factors of various pathologies of internal organs and of the severity of manifested disease. Just as in various medical fields, the possibility of supporting diagnostic capabilities through automatic computerized systems is emerging also aiming at improving diagnosis reliability and consistency [2], [3]. On the other hand, the spread of smartphones and wearable devices makes it possible to think of Apps through which patient can directly monitor specific pathologies [4]. Despite the interesting premises, mobile solutions are still rare and viewed with extreme distrust. In the present work, we want to refer to the reasons that suggest the creation of applications for tongue diagnosis based on artificial intelligence.

The paper is organized as follows. In the next section we explane how tongue image analisys could be useful for supporting the diagnosis of specific deseases. In Section 3 we refer to very recent works which use Tongue Analisys to carry out initial screening for specific pathologies. In Section 4 we put in evidence the main steps of Automatic Tongue Diagnosis System (ATDS). Finally, a discussion about the opportunity offered by Tongue Analysis and possible future developments are reported.

II. What does the tongue tell us?

According to different branches of Oriental Medicine [5] different areas of tongue reflect the functioning of internal organs (Fig. 1), in which five main areas are distinguished.

The tongue is divided transversally into three parts, each corresponding to some organs: kidneys, adrenal and intestines in the proximal third, spleen, liver, pancreas, stomach in the middle third and lungs and heart in the distal third. The median longitudinal line that divides the tongue into two represents the spinal column. The central part that covers the three sectors and the three main digestive organs, stomach, small intestine and colon, is related to the digestion phases.

Under normal conditions the tongue is slightly moist and light red in color with a thin white coating. In fact, the slightly moist tongue testifies the intact body fluid while the light red is indicative of a correct functioning of all organs. Other tongue body colors such as red, deep red, purple, and blue indicate abnormalities of specific organs.

The lining of the tongue is also of diagnostic importance. In fact, in the face of a thin white layer, indicative of a state

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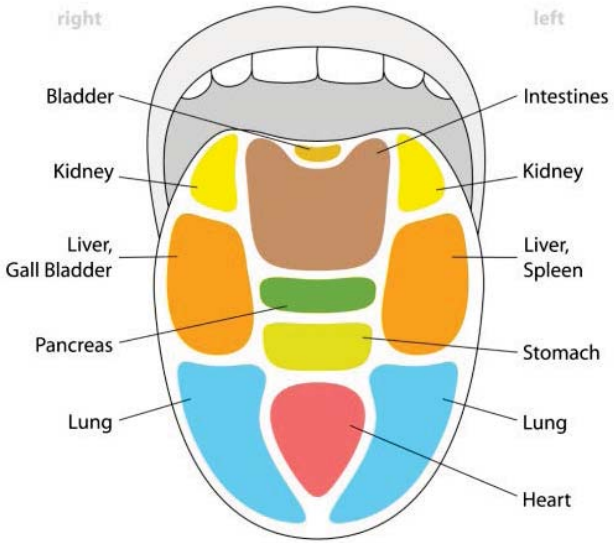

Fig. 1. Tongue Reflexology Chart

of good health, the presence of certain pathologies can imply different colors such as white, yellow, gray and black. The different staining is related to the presence of bacteria and the deposition of metabolites can provide useful information for the diagnosis of the disease [6].

In light of these assumptions, changes in the color and thickness and color of the lining of the tongue can help doctors in identifying malfunctions of patient organs, such as:

- a pale tongue can be anemia;
- a dry, red tongue without a coating may be Sjogren syndrome or yin deficiency;
- a dry, red tongue with a yellow coating may be inflammation;
- a stiff, inflexible tongue may be a stroke or internal wind injury.

However, the traditional diagnosis of tongue depends on the skill of the doctor, whose judgment is subjective, and depends on his personal knowledge and experience. Modern computer technology using Machine Learning approaches, Big Data exploiting the spread of smartphones can effectively help establish reliable diagnoses by providing standardized procedures and objective, reliable and quantified data.

III. Automatic Tongue Diagnosis System

With progresses in image acquisition hardware and pattern recognition techniques, Automatic tongue Diagnosis System (ATDS) begin to be proposed [7]. These solutions differ in terms of hardware, being able to rely on advanced models of cameras that allow to choose light source and color calibration, and software relying on different approaches for tongue segmentation, and for the extraction of features. The ATDS supports the storage and transmission of digital data, as well as image analysis. The typical schema of such a system is reported in Fig. 2 and consists of four different phases: image acquisition, preprocessing, features analysis and classification.

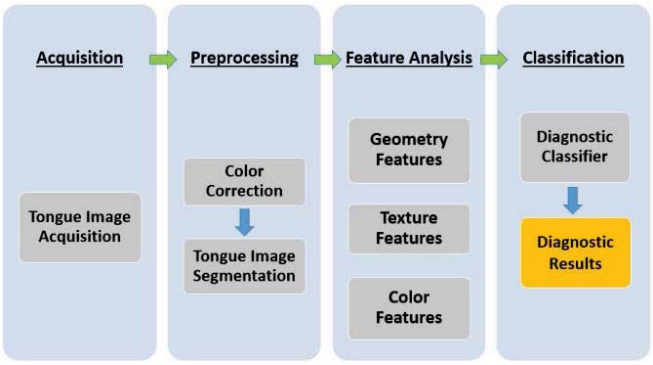

Fig. 2. Typical steps of Automatic Tongue Diagnosis System (ATDS)

The acquisition of digital images constitutes the first phase in ATDS, including many techniques useful to correctly acquire the image to be analyzed. Each of these techniques presents advantages and disadvantages that make it more or less suitable depending on the case. The most used methods for tongue image acquisition include photography, confocal scanning, laser microscopy (CSLM), ultrasound, magnetic resonance imaging (MRI). Regarding the stability of image acquisition, the calibration of brightness and color is carried out to stem the variations in intensity and color temperature of the light source and of the imaging hardware.

As already seen in other application areas, preprocessing is the stage of detection used to improve the quality of images, through color correction and removal of irrelevant noises that may cause inaccuracies in classification [8], [9]. A first goal is to separate, for example by edge detection techniques, tongue from background. The purpose of isolating the region of the tongue is to eliminate the irrelevant lower facial portions and the background surrounding the tongue, thus facilitating the identification and extraction of features. The quickest way to remove defects related to image acquisition is to use filters such as, medium filters, median filter or Gaussian filter [10]. These filters can be applied directly on grayscale images, and are applied to each channel on color images (marginal filtering).

Tongue features extraction employs criteria such as aspect ratio, color composition, position, shape and color distribution of the tongue, as well as the amount of neighboring pixels. Tipically, tongue features are of three main types, namely geometric, texture and color [11].

In particular, the most commonly used color and texture features including tongue color, tongue cleft, hair color, hair thickness, bruising, tooth mark, red dot, saliva, and tongue's shape, while the geometric features are obtained using the relative distances of length, width and area of tongue.

IV. Role of Color Features

Diseases detection can be supported by automatic images analysis using appropriate features, such as color. Color rep-

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resentation can be made in different color spaces. Typically, for automatic image analysis, the most used color spaces include RGB, HSI, CIExy, CIELUV and CIELAB. An image is commonly represented with a two-dimensional pixel matrix in which each pixel is composed of three parameters, i.e. red, green and blue (RGB). The RGB color space is often used in computer applications cause no transformation for the screen display is needed. Known the parameters of a color in a space, it is possible to obtain representation in other color spaces using appropriate transformations [12].

Color tongue gives important information concerning the presence of specific pathologies [13]. Various approaches have been proposed in order to exploit color features in tongue images analysis. One interesting approach has been proposed in [14], where the authors defined a kind of color codebook. More particularly, the color features extracted from each pixel, are assigned to 1 of 12 colors symbolizing the tongue color gamut (see Fig. 3). The tongue color gamut represents all possible visible colors on the tongue surface. Pixels or Region of Interest (ROI) of the tongue image, is associated to a vector composed of 12 values, which can be used for the classification phase.

Fig. 3. 12 colors representing the tongue color gamut [14]

In addition to the approach that involves the use of color tongue gamut, its possible to evaluate parameters like the mean and standard deviation of each color channel of a whole image or of a specific selected ROI. Multiple Instance Learning (MIL) is an emerging machine learning paradigm suitable for analyzing medical images and videos. MIL formulations of the classification algorithms detect recurrent patterns in images or videos using only globally assigned class labels. In our previous works, we have shown how, even by using only color features, it is possible to obtain classification results equal to or higher referring to any specific medical field [15]–[18]. In light of these experiences, we are considering possible applications using tongue images analysis.

V. Tongue Analisys in very recent years

There are many studies that aim at tongue analysis as a preliminary investigation to carry out initial screening for certain pathologies.

In [19], the authors use tongue diagnosis to investigate the discriminating features between patients with early stage breast cancer (BC) and individuals without breast cancer.

Tongue features for 67 BC stage 0 and 1 patients and 70 non-breast cancer individuals are extracted from the automatic tongue diagnosis system (ATDS). Nine features of the tongue are extracted for each image of the tongue, namely tongue color, tongue quality, tongue cleft, tongue fur, red dot, bruising, tooth mark, saliva and tongue shape. The extracted features are further divided according to the localized areas, i.e. spleen-stomach, liver-bile-left, liver-bile-right, kidney and heart-lung. Through the Mann-Whitney test it is shown that seven of the nine features extracted show significant differences and that a high accuracy (80% on the training set and 90% on the testing set) is achieved in classifying individuals not affected with breast cancer. TCM tongue diagnosis can serve as a preliminary screening procedure in the early diagnosis of BC in light of its simple and non-invasive nature, followed by another more accurate testing process.

The Metabolic syndrome is a morbid condition, from which starts central obesity, abnormal glucose tolerance, lipodystrophy, and hypertension. Traditional Chinese Medicine (TCM) classifies obesity as phlegm-moisture, often accompanied by blood stasis. The approach proposed by the authors in [20], involved the use of modern tongue analysis devices, heart rate variability and the CNAQ (Council on Nutrition Appetite Questionnaire) for the assessment of appetite. The study was conducted on two groups, one characterized by metabolic syndrome (MetS), the other without metabolic syndrome (nMetS). The results correlate TCM patterns, nutritional appetite, and heart rate variability in patients with metabolic syndrome. In particular, the tongue images showed that the MetS group has a different white coating from the nMetS group with white and yellow coating. Even in this case, these indications, detectable through computerized tongue analysis, can be favorably used as a discriminating element to support the diagnosis.

The development of gastritis is associated with an increased risk of gastric cancer. Currently, the diagnostic methods of gastritis, such as gastroscopy, are very invasive and unsuitable for timely monitoring of the evolution of the disease. In [21], the authors observed that the change in the tongue lining microbiota was associated with the onset and development of gastritis. Twenty-one microbial species have been identified to differentiate the tongue lining microbiomes of gastritis and healthy individuals. The presence of Campylobacter concisus, which has been shown to be associated with the gastric precancerous cascade, could be detected through an investigation conducted by analyzing the image of the tongue and its coating. The observations conducted in this study provided biological evidence of the diagnosis of the tongue in Traditional Chinese Medicine and indicated that the tongue lining microbiome could be a potential non-invasive biomarker suitable for monitoring gastritis in the long term avoiding the need for more invasive and expensive investigations.

In [22], the authors examined discriminating tongue features to distinguish between individuals with type 2 Diabetes Mellitus (DM) and non-DM. Diabetes Mellitus (DM) is associated with numerous oral complications, such as coated tongue and salivary dysfunction. The study involved the extraction of 9

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features of the tongue (tongue shape, tongue color, hair thickness, fur color, saliva, tongue cleft, bruising, tooth mark and red dot) extracted via a Automatic Tongue Diagnosis System (ATDS). Patients with type 2 diabetes mellitus had a larger coverage area of yellow fur, thick fur, and a bluish tongue than those in the control group. In addition, a significantly higher proportion of long-term diabetic patients with yellow hair color was observed than their short-term counterparts. The high prevalence of thick hair, yellow fur color, and bluish tongue in patients with type 2 DM revealed that diagnosis of TCM tongue can be useful as a preliminary screening procedure in the early diagnosis of type 2 DM.

In [23], authors purpose was to establish a quantitative model of syndrome differentiation with logistic regression analysis for Phlegm and Blood Stasis Syndrome (PBSS) in Coronary Artery Disease (CHD) in order to offer methodological guidance for quantitative differentiation of the syndrome. Starting from the use of tongue features of each subject extracted by a dedicated intelligent diagnosis tools, the diagnosis model of the syndrome was built and proved to be effective.

Tongue diagnosis has been considered a fundamental basic procedure in insomnia therapeutic decision making in Traditional Chinese Medicine (TCM). Chronic insomnia is a disease that brings intense mental pain and disturbing complications to patients worldwide. In [24], the authors used 16S rRNA gene sequencing and bio-informatics analysis to study dynamic changes in the oral bacterial profile and correlations between patients with chronic insomnia and healthy individuals, as well as in patients with different tongue coatings.

The results showed that patients with chronic insomnia harbored significantly greater diversity of oral bacteria than healthy controls and that the diversity and relative abundance of the bacterial community was significantly altered between different tongue linings in patients but not healthy individuals. Changes in the oral microbiome are related to the lining of the tongue in patients with chronic insomnia. Through specific automatic tongue diagnosis system it would therefore be possible to grasp the correlations between the tongue images and the oral microbiome in patients with chronic insomnia.

In [25], the authors investigate the association between Gastroesophageal Reflux Disease (GERD) and tongue features with the aim of assessing whether tongue imaging could serve as an initial diagnosis of GERD in a non-invasive way.

In particular, a cross-sectional, case-controlled observational study was conducted at Kaohsiung Chang Gung Memorial Hospital in Taiwan from January 2016 to September 2017. Participants over 20 years of age with GERD were enrolled and the control group without GERD was matched by gender. Tongue imaging was acquired with the automatic tongue diagnosis system, followed by an endoscopic examination. Nine tongue features were extracted and a receiver operating features (ROC) curve, analysis of variance, and logistic regression were used. It was found that the amount of saliva and the thickness of the hair of the tongue, particularly that in the spleen-stomach area, were significantly greater in patients with GERD than in those without. These features could therefore be adopted as non-invasive indicators to predict the risk and severity of GERD.

VI. Discussion and Future Work

Artificial intelligence is currently being used for medical image analysis in various fields, and particularly for organ and injury segmentation, disease detection and classification, and to assess response to treatment [26].

The MIL paradigm is particularly well suited to image classification, given that to classify an image containing an object of interest, it is necessary to examine only some subregions of the same image. With a MIL approach it is therefore possible to obtain global information from local one [27]. In [29], a detailed review is given concerning Multiple Instance Learning applied for medical images and video analysis, while in [28] various techniques of image classification task are reported.

The MIL approach, as far as we know, has not been used for Tongue Image Analysis. With the combination of the subjective clinical experience and the objective diagnostic tool of the automatic tongue diagnosis system, it is possible to identify specific tongue features for different diseases.

In order to make the population more responsible for the prevention and management of various diseases by ensuring more interactive follow-up paths between patient and doctor, there is a growing demand for remote health monitoring. The ultimate goal is to allow more accurate diagnoses already in the early stages of the pathologies and to improve the quality of health services by resorting to less invasive diagnostic processes with low costs. The automatic tongue diagnosis system can be made even more usable by thinking about solutions dedicated to mobile platforms that can take advantage of the advances in imaging sensors. Starting from better defined images, advanced image processing, feature extraction and the use of specific classification algorithms will be easier. The system indications can be shared with the medical staff or with other users as long as privacy is respected. Finally, do not overlook the opportunity of cloud computing to store images and results over time. An integrated solution can provide the contextual management of other biometric data, such as blood pressure, heartbeat, blood oxygenation, sleep cycle, body mass index currently easily detectable via smartwatch [30].

Together with tongue images captured via smartphone's camera, these bio-information could be used for analysis and monitoring, enabling automatic alerts for patient and physician if health data should result abnormal. Incorporating tongue diagnosis into various mobile health support solutions will allow for better diagnoses in various fields and will promote the spread of tongue analysis also in Western medicine. To this end, our aim is creating a module to be integrated in the software Simpatico 3d [31], [32] which is in charge of allowing a first self-screening for some pathologies, and to allow a broader vision of the patient's health status in favor of the doctors who will treat him.

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