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Instrumental intelligent test of food sensory quality as mimic of human panel test combining multiple cross-perception sensors and data fusion

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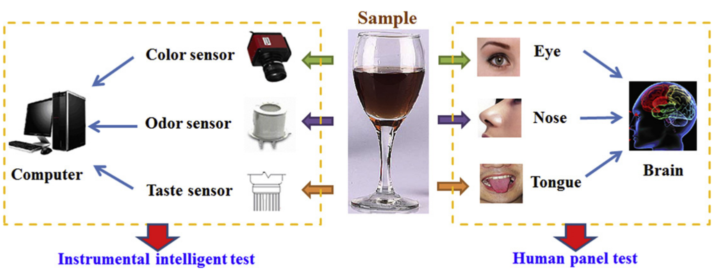
HIGHLIGHTS

- To develop a novel instrumental intelligent test methodology for food sensory analysis.
- A novel data fusion was used in instrumental intelligent test methodology.
- Linear and nonlinear tools were comparatively used for modeling.
- The instrumental test methodology can be imitative of human test behavior.

GRAPHICAL ABSTRACT



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ABSTRACT

Instrumental test of food quality using perception sensors instead of human panel test is attracting massive attention recently. A novel cross-perception multi-sensors data fusion imitating multiple mammal perception was proposed for the instrumental test in this work. First, three mimic sensors of electronic eye, electronic nose and electronic tongue were used in sequence for data acquisition of rice wine samples. Then all data from the three different sensors were preprocessed and merged. Next, three cross-perception variables i.e., color, aroma and taste, were constructed using principal components analysis (PCA) and multiple linear regression (MLR) which were used as the input of models. MLR, back-propagation artificial neural network (BPANN) and support vector machine (SVM) were comparatively used for modeling, and the instrumental test was achieved for the comprehensive quality of samples. Results showed the proposed cross-perception multi-sensors data fusion presented obvious superiority to the traditional data fusion methodologies, also achieved a high correlation coefficient (>90%) with the human panel test results. This work demonstrated that the instrumental test based on the cross-perception multi-sensors data fusion can actually mimic the human test behavior, therefore is of great significance to ensure the quality of products and decrease the loss of the manufacturers.

1. Introduction

Sensory attributes play an important role in estimation of food quality which is usually conducted by human panel test. However, the use of human for sensory evaluation entails several drawbacks such as fatigue, stress and inconsistence etc. The sensory evaluation is time-consuming and unfavorable for real time measurements. Therefore, it is very important in food industry to develop methods which can partially replace the panel during the routine work and achieve the objective measurements in a short time in a consistent and cost-effective manner [1,2]. The great advance of the so-called sensors and their growing

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applications in food analysis has attracted considerable research interest in developing alternative techniques or new applications in the field of food sensory analysis [3]. Color sensor (electronic eye, E-eye), odor sensor (electronic nose, E-nose) and taste sensor (electronic tongue, E-tongue) techniques address the senses of sight, smell and taste respectively and have been adapted as alternative instruments for food analysis [4]. Fig. 1 illustrates a comparison between the human panel test and the instrumental intelligent test for food quality.

These instruments provide data signals of food. These signals can be related to the sensory attributes and allow their characterization if suitable chemometrics techniques are applied. Previous research works revealed that these sensor technologies have capability in prediction of human sensory attributes/scores of food [5–9]: for instance, using E-nose to correlate with aroma attribute, or using E-tongue to correlate with taste attribute. Nevertheless, the complete characterization of food requires the simultaneous use of several techniques that can describe the visual, olfactory and gustatory aspects. The compilation of data coming from different sensors provides complementary interpretations and facilitates a full product description. The combination of information provided by several analytical instruments is called data fusion, which involves treating a large number of multivariate signals of a different nature. The processes are often categorized as low-level, medium-level and high-level, depending on the processing stage at which fusion takes place. The low-level fusion combines several sources of raw data to produce new raw data. The medium-level fusion combines features extracted from the signal of each sensor. While in the high-level fusion, multivariate models (e.g., classification models) are built separately for each instrumental technique and the individual classification results fused to get the final classification [10].

Rodriguez-Mendez et al. employed the medium-level fusion by combining the first principal component of the three instruments (E-eye, E-nose and E-tongue) for the analysis of the quality of red wine [11]. Apetrei et al. fused all the raw data from E-eye, E-nose and E-tongue for the characterization of olive oils with different degree of bitterness [12]. Gil-Sánchez et al. fused the raw data from E-nose and E-tongue for assessing deterioration of wine [13]. Banerjee et al. fused the characteristic variables from E-nose and E-tongue for the classification and prediction of taste scores of tea [2]. Haddi et al. combined E-nose and E-tongue using both low-level data fusion and medium-level data fusion for classification of Moroccan virgin olive oil profiles [14]. Haddi et al. also combined E-nose and E-tongue using the low-level data fusion to improve the recognition result of fruit juice samples [15]. Hong et al. detected the adulteration in cherry tomato juices based on data fusion of E-nose and E-tongue, by applying four different data fusion approaches were used in this study, including: fusing raw E-nose and E-tongue sensors data, fusing the features from principal component analysis of raw sensors data, fusing the features from factor F selection of raw sensors data, and fusing the features from stepwise selection of raw sensors data [16]. These previous studies showed that data fusion based on multi-sensor was superior to the single sensor techniques and this could provide reliable and improved results in further application. Also, it is known that the multiple mammal perception organs have cross-response to food attributes. Human brains receive information from complex stimuli like sight, hearing, touch, smell and taste of food and give a comprehensive description of food quality. Therefore, data fusion from multi-sensors imitates multiple mammal perception which presents a great challenge but a huge success in intelligent evaluation of food quality. Little or no information is available in literature about cross-response in the multiple mammal perception approach in data fusion for assessing food quality. This approach could provide a complete description of the food quality parameter of interest.

Chinese rice wine is one of the three ancient alcoholic beverages in the world [17]. The estimation of its quality is generally done by sensory analysis performed by trained panel of experts. Color (10%), aroma (25%), taste (50%) and style (15%) characters are four sensory attributes for rice wine according to Chinese official standard GB/T 13,662-2008. Color, aroma and taste are three separate attribute. While the style attribute is to assess the typicality and coordination of wine body of one type (i.e., sweet, semi-sweet, dry or semi-dry), also the overall rating of wine. The overall sensory score is used as the index for a comprehensive assessment of rice wine quality so it has immense commercial importance.

This work focused on the instrumental intelligent test of Chinese rice wine by integrating multiple analytical technologies such as E-eye, E-nose and E-tongue. A novel data fusion based on cross-perception multi-sensors for imitating human sensory test behavior was proposed in this work. The specific objectives were: (1) to evaluate the sensory attributes (scores) of rice wine samples by human panel test; (2) to merge and preprocess all the feature sensors data from E-eye, E-nose and E-tongue; (3) to obtain three cross-perception sensor characteristic variables (i.e., color, aroma and taste) by principal component analysis (PCA) and multiple linear regression (MLR); they were used as the input of the models; (4) and finally, to apply linear and nonlinear calibrations to establish the models for a comprehensive evaluation of rice wine quality.

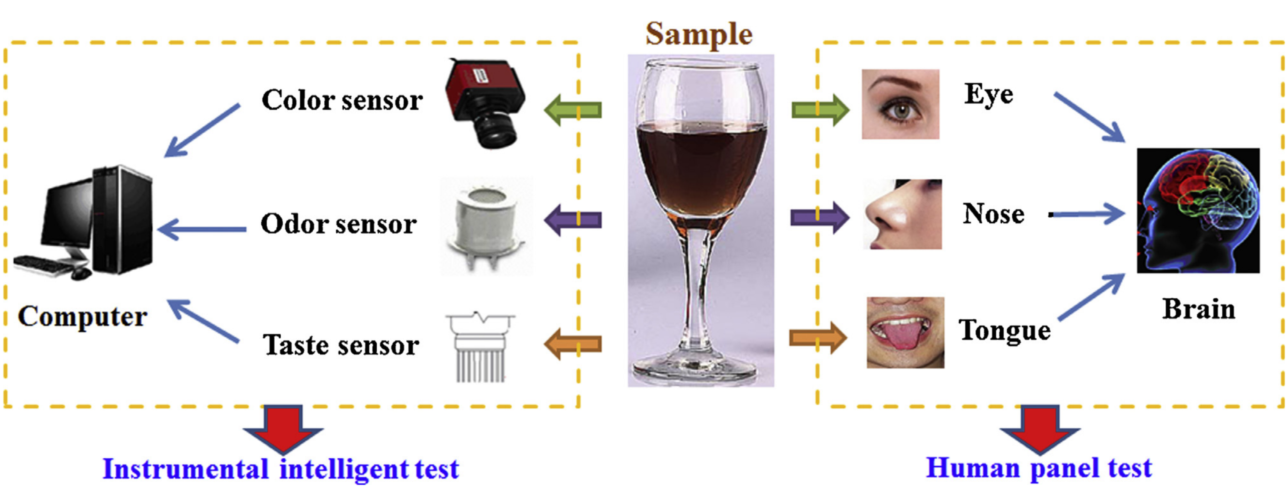

Fig. 1. A comparison between the human panel test and the instrumental intelligent assessment for food quality.