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Preemptive identification of optimum fermentation time for black tea using electronic nose

Nabarun Bhattacharya [a,*], Bipan Tudu [b], Arun Jana [a], Devdulal Ghosh [a], Rajib Bandhopadhyaya [b], Manabendra Bhuyan [c]

[a] *Centre for Development of Advance Computing (C-DAC), Kolkata 700091, India*
[b] *Department of Instrumentation and Electronics Engineering, Jadavpur University, Kolkata, India*
[c] *Tezpur University, Assam, India*

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Abstract

During black tea manufacturing, tealeaves pass through the fermentation process, when the grassy smell is transformed into a floral smell. Optimum fermentation is extremely crucial in deciding the final quality of finished tea and it is very important to terminate the fermentation process at the right time. Present day industry practice for monitoring of fermentation is purely subjective and is carried out by experienced personnel. In this paper, a study has been made on real-time smell monitoring of black tea during the fermentation process using electronic nose as well as prediction of the correct fermentation time. The study has been implemented in two steps. First, for prediction of optimum fermentation time, five different time-delay neural networks (TDNNs), named as multiple-time-delay neural networks (m-TDNN), have been used. During the second study, we have investigated the possibility of existence of different smell stages during the fermentation runs of black tea processing using self-organizing map (SOM), and then used three TDNNs for different smell stages. The results show excellent promise for the instrument to be used by the industry.

Keywords: Electronic nose; Black tea; Fermentation; Sensors; Self-organizing map (SOM); Time-delay neural network (TDNN)

1. Introduction

Black tea is produced from the plant called *Camellia sinensis*. After the tealeaves are plucked from the *C. sinensis* plant, a number of processing stages, viz., withering, pre-conditioning, cut-tear-curl operation (CTC), fermentation and drying are involved in producing finished black tea. Out of these stages, the fermentation process is extremely crucial [1], where the residence time of tealeaves on the fermentation floor, trough or conveyor plays the pivotal role in deciding final quality of finished black tea. In this process, tealeaves change colour from green to coppery brown or black and grassy smell of leaves transforms into floral smell.

The duration of the fermentation process varies due to temperature, humidity, and location of tea factory and month of the year. The optimum fermentation time for black tea manufacturing process may vary from 40 to 120 min in Indian conditions. To ensure optimum fermentation, the entire fermentation process should be carefully monitored and the process should be terminated once the optimum fermentation point is reached. To this end, it is extremely beneficial to predict the optimum fermentation time at an earlier point in time using an instrumental method. It is also observed that during the fermentation process, smell intensity is different at different instant of time and a temporal smell pattern occurs.

Electronic nose has been applied successfully for several applications related to quality of food and agro products. On black tea, pioneering work has been done by Dutta et al. [2] for classification of black tea aroma. Correlation of "tea-tasters" marks with the electronic nose signature has been successfully derived in Ref. [3]. In the previous studies by the authors [4,5], electronic nose-based monitoring of volatile emission patterns during black tea fermentation process and detection of the optimum fermentation time on the basis of peaks in the sensor outputs have been successfully achieved. Various methodologies such as singular value decomposition (SVD) and Mahalanobis distance computation

* Corresponding author at: Centre for Development of Advanced Computing (C-DAC), E-2/1, Block-GP, Sector-V, Salt Lake, Kolkata 700091, West Bengal, India.
E-mail address: nabarun.bhattacharya@kolkatacdac.in (N. Bhattacharya).

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have been made use of to evolve aroma index at any particular sniffing cycle. The computed aroma indices have been plotted against time to draw the fermentation aroma profile.

In this paper, we present the methodology and results of on-line prediction of optimum fermentation time. Because of the inherent nature of temporal pattern in the electronic nose data during black tea fermentation process, time-delay neural network (TDNN) has been selected for the on-line prediction [6]. Our approach is somewhat similar to [7], where multiple classifier system has been applied on olfactory signals, but we have used only TDNN models for the prediction. Multiple-TDNN architectures, named as m-TDNN, have been constructed and on-line switching between these networks is done as the fermentation process progresses. Each TDNN comprises of different training sets of data. For example, the first (TDNN 1) model is trained by first 20 min of data collected from electronic nose during the process of fermentation, second one is trained by first 25 min of data and so on. In the second step of our study, unsupervised method of clustering, the self-organizing map (SOM) has been applied for investigating the existence of smell stages. Four distinct smell clusters have been obtained on the data for all the fermentation runs, out of which the last stage represents over-fermentation. The first three clusters have been modeled by three independent TDNN algorithms for the prediction of the optimum time of fermentation. The novelty of the method is that this is the first attempt towards on-line prediction of optimum fermentation time during black tea processing using an electronic nose and is expected to be extremely beneficial for the user industry.

2. Customized electronic nose for black tea fermentation

An electronic nose uses an array of non-specific broadly tuned sensors to discriminate odours by analyzing sensor array data with pattern recognition methods [8]. A customized electronic nose set-up has been developed such that the same can be used in production floor of tea processing units for monitoring of volatile emission pattern during the fermentation process. The electronic nose consists of (a) sensor array, (b) micro-pump with programmable sequence control, (c) PC-based data acquisition and (d) olfaction software as illustrated in Fig. 1.

For black tea, an array of metal oxide semiconductor (MOS) sensors has been used for assessment of volatiles in the set-up. A series of experiments were carried out using a number of commercially available MOS sensors. From the response sensitivity of individual sensors, a set of eight gas sensors from Figaro, Japan (TGS-832, TGS-823, TGS-831, TGS-816, TGS-2600, TGS-2610, TGS-2611 and TGS-2620) has been selected for odour capture in fermentation process of black tea. The outputs of the sensors are acquired in the PC through PCI data acquisition cards. The MOS sensors are conductometric in nature, and their resistance decreases when subjected to the odour vapour molecules. The change in resistance with respect to their original values ($\Delta R/R$) is converted into voltage and then taken to the PC through analog to digital converter cards for subsequent analysis in the computational models.

The experimental sniffing cycle consists of automated sequence of internal operations: (i) headspace generation, (ii) sampling, (iii) purging and (iv) dormancy before the start of the

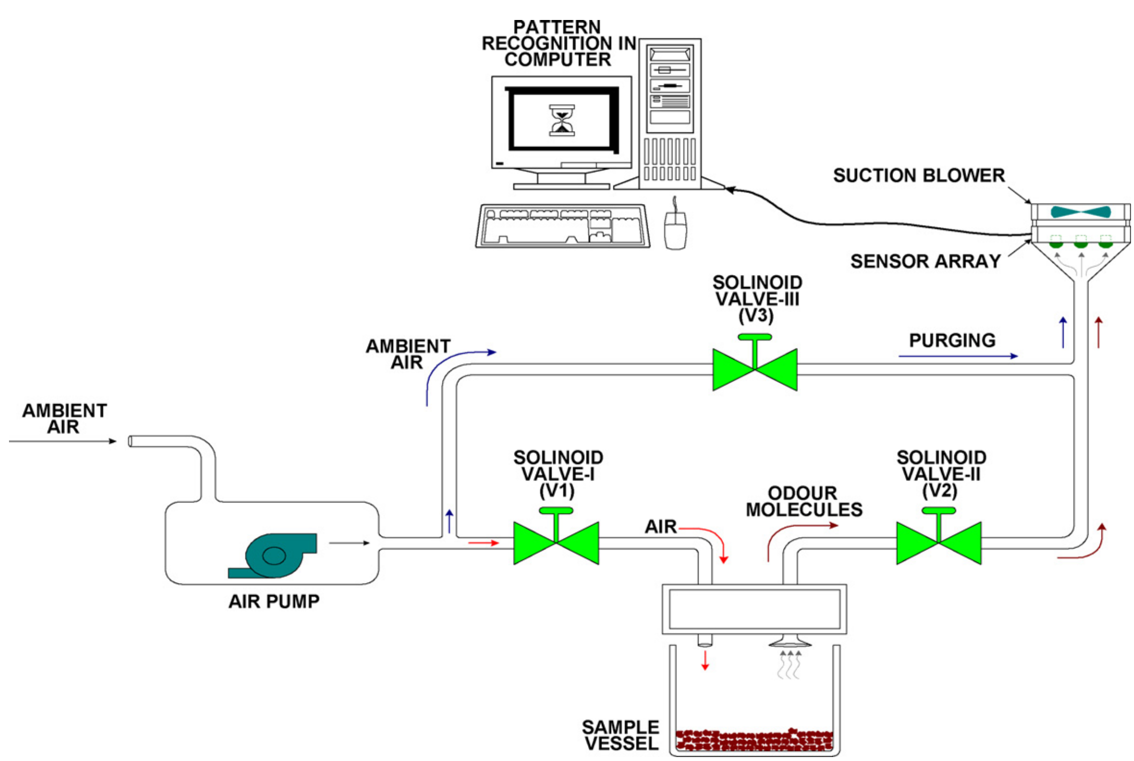

Fig. 1. Customized electronic nose set-up.