Application of Screen-Printed Taste Sensor for Quality Control of Milk Freshness

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Abstract - A disposable taste sensor fabricated using screen-printing technology was developed to test various types of commercial milk products. The array of sensors composed of several kinds of lipid as transducers and a computer as data analyzer could detect taste in a manner similar to human gustatory sensation. The sensing principle of the screen-printed taste sensor was based on measurement of the electrical potential resulted from interaction between lipid membranes and taste substances. Coupled with pattern recognition tools namely Principle Component Analysis (PCA) for non-supervised technique and Discriminant Analysis (DA) for supervised technique, it displayed the capabilities of the sensors. In the present study, two types of packaged commercial milk, the ultra high temperature (UHT) and the pasteurized milk were tested using the disposable taste sensor. The study showed that different brands of milk were easily distinguished by DA and the classification between fresh and spoiled milk were projected using PCA. The taste sensor was also used to follow the deterioration of the quality of milk when it is stored at room temperature. The data obtained were treated with principal component analysis and the deterioration pattern could clearly be followed in the diagrams. This research could provide a new monitoring method ideally for simple and cheap decentralized testing for controlling the quality of milk which may be of great use in the dairy industries.

Keywords : Disposable taste sensor; Milk quality control; Pattern recognition

1. Introduction

Multi component analysis based on chemical sensor arrays combined with appropriate chemometric methods (pattern recognition) has attracted considerable interests of many in the various disciplines. The sensorial analysis based on the sensors array and pattern recognition algorithms seems to be very promising encountering the aforementioned advantages for food and beverages analysis. It is obvious that by combining a number of non-selective sensors, the combined sensors signals yield more information about a particular sample than an individual sensor signal would. By providing global information about the sample rather than separating or measuring specific components or parameters, these holistic approach could be utilized for on-line quality control and process monitoring [1]. The advent of 'Taste Sensor' opened the way to a new kind of analytical approach of complex samples based on synthesis of global chemical information [2]

A preliminary study towards the development of a simple but reliable, one-shot, disposable 'taste sensor' system which functions on a new concept of global selectivity is currently under development by Universiti Sains Malaysia. The disposable 'Taste Sensor', coupled with pattern recognition tools is capable of providing chemical fingerprint that represent a combination of all the chemical components, ideally suitable for simple, real-time testing and monitoring the quality of food or beverages. The disposable 'Taste Sensor' is a replacement to the conventional electrodes, which is bulky and expensive. The sensor array is an integration of working electrodes and reference electrode together in one device based on screen printing technology, in order to miniaturize and to simplify the instrument for the extend of decentralized analysis [3]. The disposable 'taste sensor' system consists of an array sensor based on lipid membrane electrodes, multi-channel high impedence data acquisition and pattern recognition tools.

Food shelf life especially dairy products such as fluid milk varies with the age and type of ingredients, the

process, the packaging, the environmental conditions during distribution, and consumer holding. Manufacturers can control the first three factors to ensure the initial quality of the product but however the last two conditions are not within their control. The "freshness" or "quality" of beverage products ultimately depends on existing distribution, marketing systems and consumer food storage habits. At the point where products move from manufacturer to regional distribution centers, temperature or humidity changes will cause abuse to products resulting in quality loss. Hence, product code date such as sell-by-date or use-by date which manufacturer put on packages to give consumers information about product freshness can't always be equated with it's potential shelf life. Therefore, it is necessary for the description or monitoring of analysis pertaining to quality assurance. The present paper is devoted to analytical evaluation of the disposable 'Taste Sensor' capable of distinguishing between fresh and spoiled milk and to follow the deterioration of the quality of milk when milk is stored at room temperature. The system has been tested on two types of commercial milk, the Ultra High Temperature (UHT) milk and the pasteurized milk.

2. Materials and Methods

2.1 Disposable Taste Sensor by Screen–printing technology

The design and fabrication of the disposable taste sensor were carried out in Universiti Sains Malaysia with the help from Scrint Technology Corp. Malaysia. Screen-printing technology is a technique whereby the screens allow ink to be applied on to a substrate with a squeegee in a particular size, shape and sequence of the print. Each of the screen-printed electrodes was printed in an array of eight tracks of working electrodes and a track printed with Ag/AgCl, as the reference electrode.

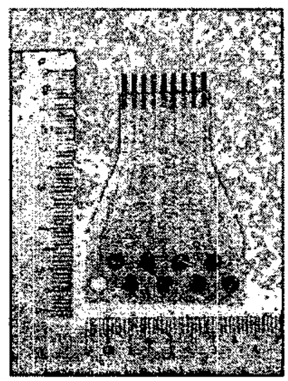


Figure 1 Top view of a miniature disposable sensor fabricated by screen-printing technology

The sensing part is an array of several different sensing elements of lipid/polymer membranes electrodes, each with different characteristics. The lipid membranes used are similar as reported by Toko [4]. The final step of the fabrication of these disposable strips for the taste sensor is the deposition of the lipid membranes with a dispenser onto the grooves of the working electrodes of the array. Fig.1 shows the disposable taste sensor with lipid membranes dispensed at the working electrode and a reference electrode integrated into one device. Fig.2. shows the disposable taste sensor system.

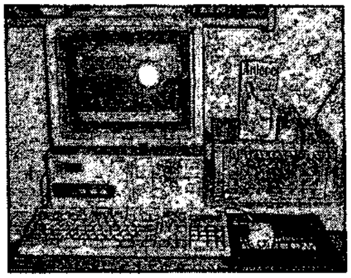


Figure 2. The disposable taste sensor system

2.2 Milk measurement

Samples of both pasteurized and UHT milk were brought over the counter. As a primary test, system competence to categorize different brands of packed milk has been evaluated. Measurements were performed on several brands of UHT and pasteurized milk. At the second stage, the evaluation of the disposable taste sensor system for fresh-spoiled milk has been carried out. Three sets of measurements consists of four different brands of milk were collected immediately after the package was opened and then held opened, at room temperature for 48 hours, and then measured again.

At the third stage, only one brand out of the four brands was selected from each type of milk. Randomly, we have chosen Anlene brand for UHT milk and I Cal for pasteurized milk. The first measurements were taken during the first hour of opening and later at the 6th hour, 12th hour, 16th hour, 24th hour, 26th hour and finally on the 48th hour when the milk was surely spoiled. Data collections were repeated eight times for both samples except for the last measurement (taken on the 48th hour) where only three sets of data were collected. The disposable sensors were washed with distilled water before they were being immersed into the samples. One minute of conditioning was performed before data collection started and all measurements were taken for sixty seconds with ten seconds of interval.

2.3 Data analysis

The raw data obtained from the experiments were treated by pattern recognition principles namely principle component analysis (PCA) and Discriminant Analysis (DA). All PCA and DA were performed with the software packaged SPSS 9.0 for Windows. PCA is a mathematical transform, which is used to explain variance in experimental data [5]. PCA reduces the immense data set to plots, which can be easily used to classify or group the observation. DA is a supervised technique. Unlike PCA, DA knows the class membership of the treated data and will try to classify them best. DA is used to check the differences among groups and to test theory by observing whether cases are classified as predicted [9].

3 Results and Discussion

3.1 Classification of different brands of UHT and pasteurized milk

Fig 3 (a) and (b) illustrated plots of the first two functions for different brands of commercial UHT and pasteurized milk available in the market. As can be observed, the first discriminant function distinguished rather well among those different brands of milk. Three different clusters of UHT and pasteurized milk samples can be easily grouped to their respective brands.

3.2 Classification between fresh and spoiled UHT and pasteurized milk

At the second stage, measurements were taken from four different brands of packaged Ultra High Temperature (UHT) and pasteurized commercial milk. Figure 4a. and 4b. show the response patterns for fresh and spoiled milk in one of the samples of pasteurized milk - I Cal as an example. As can be seen, both patterns impart two different unique fingerprints, which differ the fresh milk from the spoiled one. Three measurements of the same brand of milk have been performed to ensure the repeatability of the disposable strips. The standard deviation between the three different measurements for channels 1 to 8 respectively was about 2mV-6mV for fresh I Cal milk and 1mV-12mV for spoiled I Cal milk. The original data obtained from the measurements of the UHT and pasteurized milk were visualized using principal component analysis (PCA), (Fig. 5). PCA aims at reducing the dimension of data without losing information. Principal component analysis (PCA) is an unsupervised method and is used to decide whether a set of pattern classify naturally into groups. Therefore, PCA is able to highlight some clusters without having any prior knowledge of the classes to be expected and it can prove the performance of the system [6].

Fig. 5. present the principal component analysis (PCA) plots discriminating between the fresh and spoiled samples. Table 1 shows the eigenvalue and percentage variance of the response data. The first three principal components contained more than 85% of total variance and eigen values of greater than 1. These three principal components have the most relevant information to classify the fresh milk from the spoiled ones. In Figure (5à) and (5c), principal components 1 (PC1) vs. principal components 2 (PC2) are shown, together explaining 73.2% of total variance for UHT milk and 73.9% for pasteurized milk. Besides, it is found that plots for PC1 vs. PC2 and PC1 vs. PC3 showed similar tendencies shown in Fig 5a with 5b and Fig 5c with 5d), whereas for PC2 vs. PC3, these tendencies were less clear (as illustrated in the below Fig 6(a) and (b)). As can be observed from Fig 5., a clear distinction between the fresh and spoiled data for both pasteurized and UHT milk is achieved. The plots are divided into two region with principle component 1 discriminates between the two classes. The upper region of the zero axis indicates the region for spoiled milk whereas the lower one indicates the region for fresh milk. The arrows showed the transition passage from fresh to spoiled product for each milk sample.

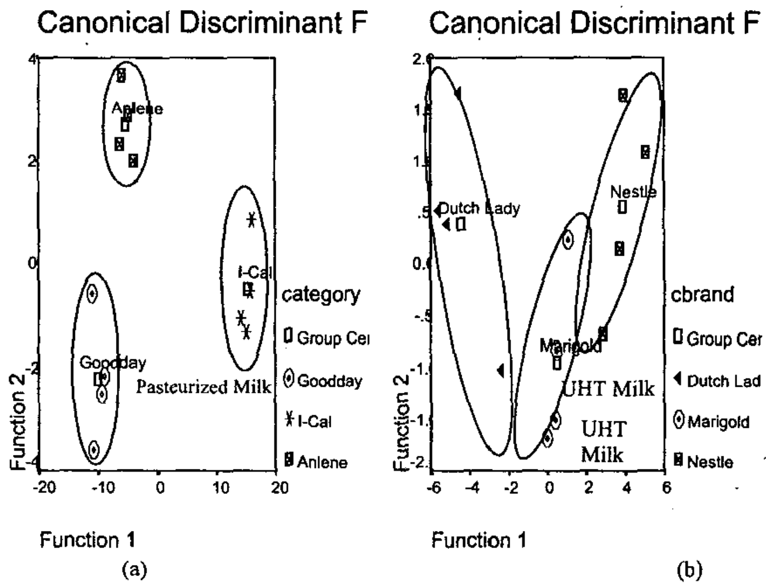


Figure 3 Discriminant abilities of screen-printed taste sensor system in different types of package milk. Data processing has been performed by DA

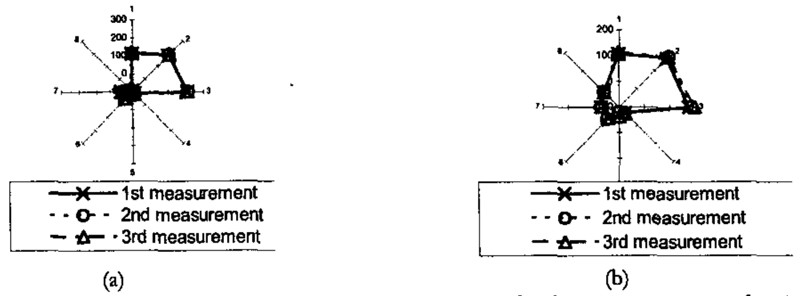


Figure 4 Response pattern of disposable sensor array for three measurements of (a) I Cal fresh (0 hour) pasteurized milk and (b) I Cal spoiled (48 hours) pasteurized milk

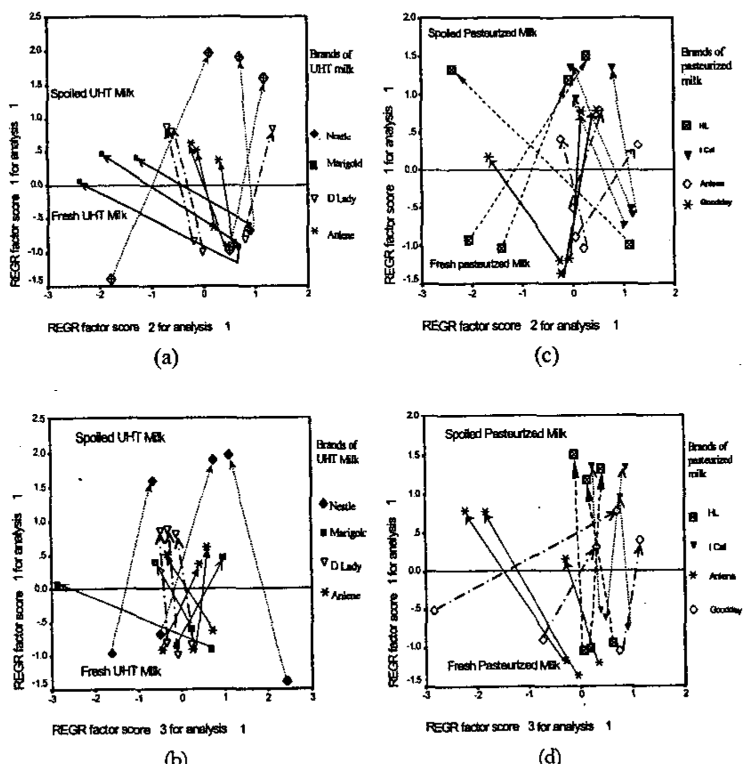


Figure5 Discriminating abilities of the disposable 'Taste Sensor' system between fresh (0 hour) and spoiled (48 hours) milk (a)(b) UHT Milk and (c)(d) Pasteurized Milk

4 The evolution with time of milk quality

The third part of the present work has been designed as an attempt to monitor the deterioration of the quality of milk due to microbial growth when milk is stored at room temperature. A detailed study has been performed using the UHT and pasteurized milk and the PCA plots which display the results of the milk analysis are shown in Fig. 7(a) and (b). A dependence of disposable sensor array data on milk storage time can be observed. The principal component analysis of the milk freshness data matrix showed a characteristic development of the milk quality dependent on storage time. The first and second principal component described 66.1% of total variance for UHT milk and 66.8% for pasteurized milk. The plots can be divided into three parts. With increasing storage time, the PCA plots extend from right lower corner through the middle and to the right upper corner of the plots in both the above figures. An interesting observation can be made; the position of the samples (although partly of them are overlap) follows a path that bend upwards with the time order. The 'freshness maps' shown reflect the deterioration process or evolution features of milk quality with time due to microbial growth The system appeared to category of the aging process of milk. Rapid evolution of milk quality can be observed in the starting period of storage time due to the distance of the data points, which are quite far from the others. The second data range (6^{th}-26^{th} hour) is less evolving, thus indicating slow variations of milk quality. The last points are taken on the 2^{nd} day when milk was surely spoiled and the points shown are distant from the others. Changes in milk quality due to bacterial deterioration are quite subtle and it occurs well before any physical changes can be noticed and as such, it can be evidence that the disposable taste sensor is able to trace evolution quality of milk As the present work is only a preliminary approach, we proposed that further research in this direction should be widened in future in order to keep perishable food remains of satisfactory quality for consumer to purchase.

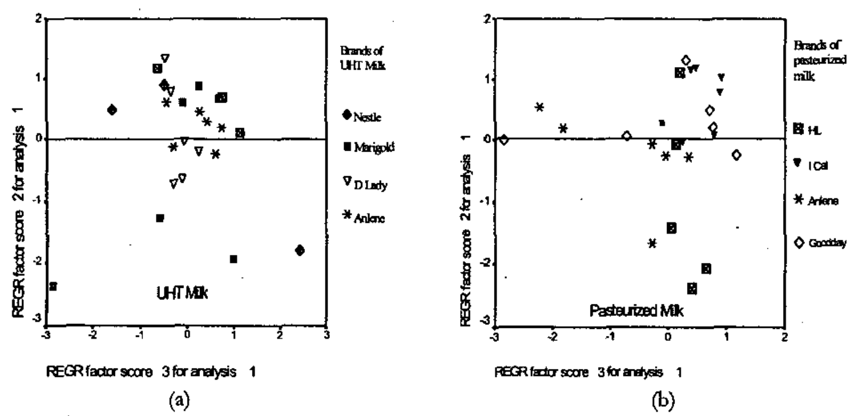


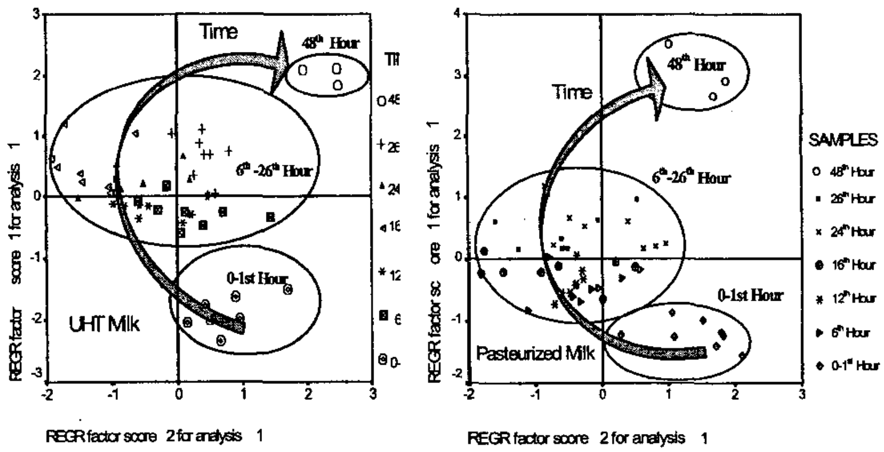
Figure 6 'Score plots' of a principal component analysis with the second principle component vs. the third principle component for fresh-spoiled (a) UHT and (b) pasteurized milk data.

Table 1: Eigen value and percentage variance of the PCA analysis of response data

UHT Milk				Pasteurized Milk			
Component	1	2	3	Component	1	2	3
Eigenvalue	4.017	1.842	1.090	***Eigenvalue***	4.185	1.564	1.061
% of Variance	50.207	23.026	13.628	% of Variance	1.564	19.548	71.855
Cumulative %	50.207	73.233	86.861	Cumulative %	1.061	13.258	85.113

4. Conclusion

Primary results presented in this paper show the utility of the disposable taste sensor system for testing and monitoring the quality of milk for human consumption. The PCA method permits a good classification between the fresh and spoiled milk. In the case of monitoring the milk quality when it is stored at room temperature, the disposable taste sensor system together with pattern recognition technique, PCA is able to show a characteristic development of the milk quality dependent on storage time. In conclusion, the system described may be of great use in the dairy industry. However the field of applications may further be widened and thus, it might become a challenging promise for the food and beverages industry.



(a) (b)

Figure 7 'Score plots' of a principal component analysis. First and second principal component correlated with the storage time. (a) UHT Milk and (b) Pasteurized Milk

5. Acknowledgement

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6. References

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