Prediction of Microbial Spoilage and Shelf-Life of Bakery Products Through Hyperspectral Imaging

03CS6901 Seminar I

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C E R T I F I C A T E

This is to certify that, this report titled ***Prediction of Microbial Spoilage and Shelf-Life of Bakery Products Through Hyperspectral Imaging*** is a bonafide record of the **03CS6901 Seminar I** presented on March 15 2021 by

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scholar, under our guidance and supervision, in partial fulfillment of the requirements for the award of the degree, **M. Tech. Computer Science & Engineering (Image Processing)** of **APJ Abdul Kalam Technological University**.

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Abstract

Bakery products have become an integral part of the majority of the world population's daily routine and liked by all.Every bakery products have a predefined shelf life. The shelf life of bakery products highly depends on the environment it is placed and it may get spoiled earlier than its expiry which results in food-borne diseases and may affect human health or may get wasted beforehand. The traditional spoilage detection methods are time-consuming and destructive in nature due to the time taken to get microbiological results. The proposed method presents a novel method to automatically predict the microbial spoilage and detect its spatial location in baked items using Hyperspectral Imaging (HSI) range from 395-1000 nm.This approach can detect the spoilage almost 24 hours before it started appearing or visible to a naked eye with 98.13% accuracy on test data. A spectral preserve fusion technique has been adopted to spatially enhance the HSI images while preserving the spectral information. To automatically detect the spoilage, Principal Component Analysis (PCA) followed by K-means and SVM(Support vector machine) has been used.

Contents

Chapter 1

Introduction

Baked products especially bread and sponge cakes are popular and high in demand due to its nutritional, taste, and appearance qualities.Every baked products has a predefined shelf-life depending upon the type of ingredients used in it or the environment it is placed. The variations in the estimated shelf-life of bakery products may result in two ways such as Moderate environment and Extreme environment. In moderate environment the growth of bacterial microorganisms gets slow-down which results in enhancing the shelf-life. On the otherhand extreme humid or drier environment results in affecting the moisture content of the product which may lead to the early spoilage. Therefore, the food-item gets spoiled before its expiry.World Health Organization (WHO) estimated that almost 33 million years of healthy lives have been lost due to the consumption of unhygienic food. Food-borne diseases are mostly due to microbial spoilage.Therefore, early detection of food spoilage has utmost importance.

Hyperspectral imaging (HSI) is widely used in the food sector. HSI is a non- destructive technique that can be used to automatically detect and predict the microbial spoilage in bakery products. Hyperspectral imaging is the capturing and processing of an image at a very large number of wavelengths. The light striking each pixel is broken down into many different spectral bands inorder to provide more information of what is imaged. Hyperspectral images have hundreds or thousands of bands.The hyperspectral imaging measures the continuous spectrum of the light for each pixel of the scene with fine wavelength resolution, not only in the visible but also in the near-infrared[2]. HSI captures data in the form of a hypercube by storing it in two spatial coordinates (x and y) and one spectral dimension [3].The spectral dimension of a hypercube describes the capability of an HSI system to store the nature of an object corresponding to each wavelength.

The objective of this method is to detect and predict the spatial location of microbial spoilage in cake sponges using Hyperspectral imaging. The analysis of microbial change in baked cake sponges has been made spatially, therefore the size of the cake images needed to be the same. While with time, the cake sponges change size due to the enhancement or reduction of moisture content. Therefore, a spectral preserve hyper sharpening technique has been used to spatially enhance the HSI images while preserving the spectral information. Total of 16 HSI data samples have been acquired over the span of 8 days with a 12 hours difference in each sample. This method detect the spoilage almost 24 hours before it started appearing or visible to a naked eye with 98.13 perecentage accuracy on test data.In this approach it consist of methodologies such as sample preparation, data acquisition, spectral preprocessing, hypersharpening,microbial spoilage detection and model training using Support vector machine(SVM).

Chapter 2

Literature survey

1. **D. Vakhare, A. Gupta, and S. R. Chaphalkar,"Confocal microscopy and its implementation in different biological aspects"** [4],Emergent Life Sci. Res.,vol. 2, pp. 8-12, Dec. 2016.

   Here adopted a popular microscopic technique called confocal microscopy.It is used for imaging fluorescently labelled specimens with significant three-dimensional structure and has shown various applications in clinical sciences and life sciences comprising imaging of the structural distribution of macromolecules in living cells, three dimensional programmed assortment of data, imaging of numerous labelled specimens and the assessment of physiological movements in living cells. The confocal microscopy is based on the point illumination, here a laser beam is focused on a fluorescent specimen through the objective lens. The reflected and emitted light is captured by the same objective. Reflected light is deviated by the mirror while the emitted fluorescent light passes through a pinhole to decrease the "out of focus" light. The focused light passes through emission filter and proceeds to the photomultiplier. Then the single point scanned in an X-Y manner as the laser focus is moved over the specimen for entire image generation. Laser scanning of the confocal microscopy enables to recognize the living microbes within their habitat.Thus, it has been used to detect the early growth of bacterial micro-organisms to prevent the negative effects of consuming exposed food items.

2. **Y. Zhang, L. Zhu, P. He, and Q.Wang,"Simultaneous detection of three foodborne pathogenic bacteria in food samples by microchip capillary electrophoresis in combination with polymerase chain reaction"** [5],Journal of Chromatography A, vol. 1555, pp. 100-105, Jun. 2018

   Here presented a rapid and sensitive detection strategy based on Microchip capillary electrophoresis MCE was developed and applied to simultaneously detect PCR products of three foodborne pathogenic bacteria. Three pairs of primers were specially designed for the amplification of target genes from Escherichia coli (E. coli), Staphylococcusaureus (S. aureus) and Salmonella enterica serovar Typhimurium (S. Typhimurium). The PCR productsalong with standard DNA fragments were employed to optimize the separation conditions in MCE. DNA is considered an ideal molecule for detection of specific foodborne bacteria and provides clear biological information.Therefore, Polymerase chain reaction (PCR) based techniques in combination with separation technologies have been used for rapid amplification and detection of many different bacteria.Also the application of MCE is relatively excellent in microbiological research. The results proved that MCE is a potentially efficient and reliable assessment approach for foodsafety since it offers the advantages of high sensitivity, high speed,low reagent consumption and rapid operation.

3. **M. Gallo, L. Ferrara, and D. Naviglio,"Application of ultrasound in food science and technology: A perspective"** [6],Foods, vol. 7, no. 10, p. 164, October 2018.

   Here ultrasound technology have been used in the characterization of food quality.Ultrasound is composed of mechanical sound waves that originate from molecular movements that oscillate in a propagation medium. Ultrasound has been applied to food technologies due to its mechanical or chemical effects on the processes of homogenization, mixing, extraction, filtration,crystallization, dehydration, fermentation, modulation of the growth of living cells, cell destruction and dispersion of aggregates. The US energy is applied to improve the qualitative characteristics of high-quality foods and to ensure the safety of a vast variety of foodstuffs, minimizing any negative effects on the sensory characteristics of foods. US play an important role in the changes in the quality of a food during its transformation.

4. **M. S. Andresen, B. S. Dissing, and H. Loje,"Quality assessment of butter cookies applying multispectral imaging"** [7]. Food Sci. Nutrition, vol. 1, no. 4, pp. 315-323, Jul. 2013

   Here a method for characterization of butter cookie quality by assessing the surface browning and water content using multispectral images is presented. The purpose of this work was to investigate the use of multispectral image analysis to assess multiple quality aspects of bakery products from the same image. The investigated product is a butter cookie, and the investigated quality parameters are the surface browning and the water content after cooling. The investigation is focused on the influence of baking time and oven temperature on browning and moisture content. Here two cookie data sets are used.The first set, Set 1, was prepared and used for sensory evaluation and model development with regard to the browning score.The second set, Set 2, was used to validate the browning model, build the browning response surface model, and to build and validate the water content model. Cookies were accessed on three different levels (under baked, adequate, and over baked) by determining the water content in samples.

5. **A. Polak, F. K. Coutts, P. Murray, and S. Marshall,"Use of hyperspectral imaging for cake moisture and hardness prediction"** [8], IET Image Process., vol. 13, no. 7, pp. 1152-1160, May 2019.

Here a novel application of HSI is used for analysing baked products, with a focus on addressing the challenge of simultaneously measuring both the moisture content and hardness of baked sponges in a stand-off and efficient way. To allow efficient data capture, a total of 96 circular sponge cakes – of which 48 were composed of white, plain sponge and 48 were composed of brown, chocolate sponge were collected and stored immediately after baking over a period of six weeks. During data acquisition, reflectance data was captured in the form of hyperspectral images containing 256 spectral bands over 800 nm ranging from 900 nm to 1700 nm.This application has established a proof of concept for a new stand-off cake moisture and hardness monitoring system. The developed model performed well for white sponge cakes as compared to chocolate ones.

Chapter 3

Microbial spoilage prediction through Hyperspectral imaging

This method aimed to automatically detect and predict the microbial spoilage in bakery products, also its spatial location through Hyperspectral Imaging technique.It is used to detect the spoilage almost 24 hours before it started appearing or visible to a naked eye with 98.13 percentage accuracy.

This approach consist of following methodologies :

- Sample preparation.
- Data acquisition.
- Spectral pre-processing.
- Hyper sharpening.
- Microbial spoilage detection.
- Model training using SVM.

3.1 Hyperspectral Imaging (HSI) System

A Specim FX-10 Hyperspectral camera is used to acquire the samples. This camera can capture a visible and near infra-red (VNIR) electromagnetic spectrum ranging from 395 - 1000 nm with a spectral sampling of 2.7 nm with a total of 224 spectral bands. The lab scanner consists of three halogen lamps used for illumination and a translational platform of size 21cm-40 cm which is controllable through a computer via the serial communication port.The camera is mounted on a lab scanner at 30 cm high above the moving tray. HSI captures data in the form of a hypercube by storing it in two spatial coordinates (x and y) and one spectral dimension. The spectral dimension of a hypercube describes the capability of an HSI system to store the nature of an object corresponding to each wavelength.

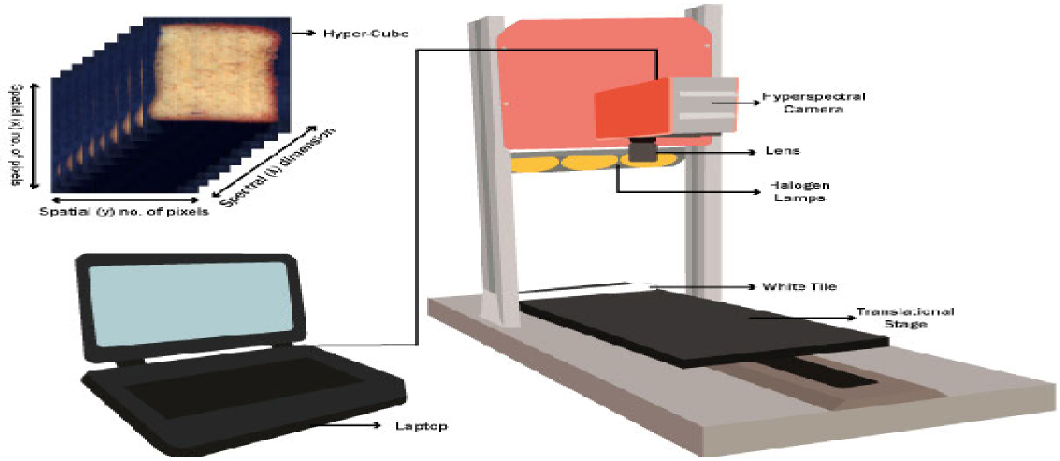


Figure 1: Hyperspectral imaging system

Sponge cake samples were used for analyzing the microbial spoilage growth. Sample cake mixture for experimental process was prepared and baked in a pre-heated microwave oven at 180 degree Fahrenheit.The samples were cooled down at room temperature and wrapped with a plastic sheet to avoid contamination from dust in the air and then stored in an airtight box. A temperature sensor was fixed within the box to determine the current and the average temperature over the span of 8 days. Data acquisition was made after every 12 hours and the samples were sprayed with distilled water mist after every acquisition to increase the moisture content to grow the microbial spoilage bacteria in cake sponges. Finally, a total of 16 samples were acquired over a span of 8 days. The false-color image of the sample was generated by choosing the red band at 699.09 nm, green at 591.04 nm, and blue at 450.16 nm. Three halogen lamps were used as a light source.

3.2 Spectral-Spatial Pre-processing

The HSI system records radiance of sample along with background and reference material. To standardize the dataset and to reduce the computational cost, samples were segmented from the background using thresholding and morphological operations.The reflectance of each sample was calculated using an empirical line method. HSI system acquires a hyper-cube by the information reflected from the sample along with environmental effects. These effects can create false results in the study about the pure nature of the sample. Therefore, the data needs to be corrected and the reflectance need to be calculated. Calculating actual reflectance is one of the major steps in data pre-processing.Darkest pixel (DP) subtraction method which utilizes the external dark and white reference along with a sample object to remove the sensor effect and camera optics from raw data. The dark reference image (D) is acquired with a closed camera aperture and completely covering the lens with the cap. The white reference image (W) was obtained by placinga white tile which has almost 99.9 percentage reflectance.

The calibrated image (IR) was calculated by using the following equation,

$$IR = \frac{I_0 - D}{W - D}$$

where,I_0 is original raw hyper-cube, W is white reference image and D is dark reference image.

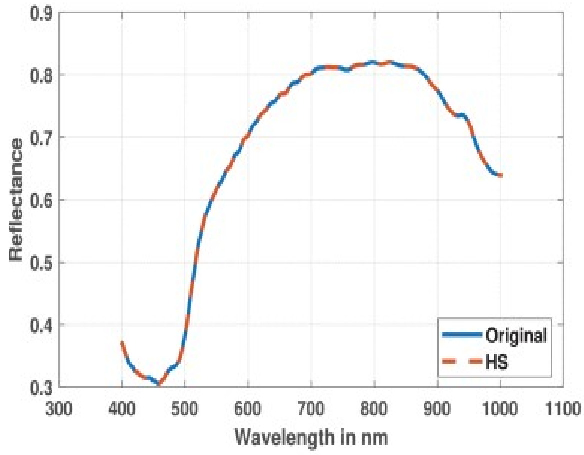
3.3 Image Fusion to Enrich Spatial Resolution

Cake sponges tend to change their size with respect to the number of days. If the surrounding is humid the size may increase due to moisture content whereas, if the surrounding is warmer and drier, it may shrink in size due to the decrease in moisture. This is important to analyse as it detects and predict the spoilage spatially as well as spectrally.To ensure that each acquired sample is co-registered with the rest of the samples, an image fusion technique is proposed.

3.3.1 Image fusion technique

The Image fusion process is defined as gathering all the important information from multiple images, and their inclusion into fewer images, usually a single one. This single image is more informative and accurate than any single source image, and it consists of all the necessary information. The purpose of image fusion is not only to reduce the amount of data but also to construct images that are more appropriate and understandable for the human and machine perception. The fused image can have complementary spatial and spectral resolution characteristics. However, the standard image fusion techniques can distort the spectral information of the multispectral data while merging.[9]

Hyper Sharpening (HS) method is used to enrich the spatial resolution of cake samples which varies in size over time. HS enhances the low-resolution image by multiplying its up-scaled version with a ratio between the high-resolution image and its downscale filtered version. The high-resolution image is obtained by selecting the bands with correlation analysis.HS has enhanced the sample image spatially while it has also preserved its spectral resolution with very little error.



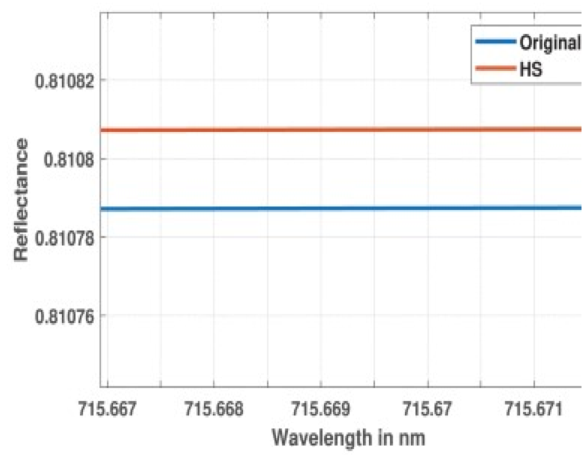


Figure 1: Left: the original and enhanced spectra of the sample; Right: the zoomed version of the difference between both original and enhanced spectra of the sample.

3.4 Microbial Spoilage Detection

Microbial spoilage results in the growth of microorganisms that produce enzymes that leads the food item to become harmful for consumption [10]. The growth of bacterial organisms can be considered as a change if the microbially exposed sample is compared to the fresh sample. Hence growth of bacterial organisms is detected by change detection technique. Here , unsupervised change detection is used.It primarily consist of the automatic analysis of the change by constructing the differenced data of temporal images. The differenced image is constructed by subtracting (pixel by pixel) two images taken at different times. The computed differenced data is further analyzed to obtain the exact changes that occurred. In this the difference images are used to derive a reduced subspace having maximum correlated data by applying PCA. The differenced image contains the data scattered over 224 bands and to process this information effectively, data size need to be reduced while preserving the maximum information. Therefore, a linear transformation based method i.e., PCA is deployed to reduce the high dimensionality.[11]

PCA first calculate the mean of every direction and computes the covariance matrix of the whole dataset as expressed in,

$$cov_{x,y} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{n-1}$$

If x and y are the same then the covariance will be the same, while it is zero if x and y are uncorrelated [12]. The positive covariance shows that x and y both are large while the negative means that x is large while y is small.

K-means clustering has been used to differentiate both healthy and unhealthy samples. K-means partitions the data points into a specified k distinct non-overlapping groups (clusters).Each data point belongs to only one cluster. Clusters are used to interpret the healthy and unhealthy(spoiled samples) for classification.To classify a sample into a healthy or microbially spoiled, SVM classifier has been used.SVM plots the data in n-dimensions and draws a decision boundary, also known as hyper-plane, to separate classes. The n-dimensions are determined by the number of classes or features exits in data.SVM finds the best optimal hyperplane that can maximally divide the data.

Chapter 4

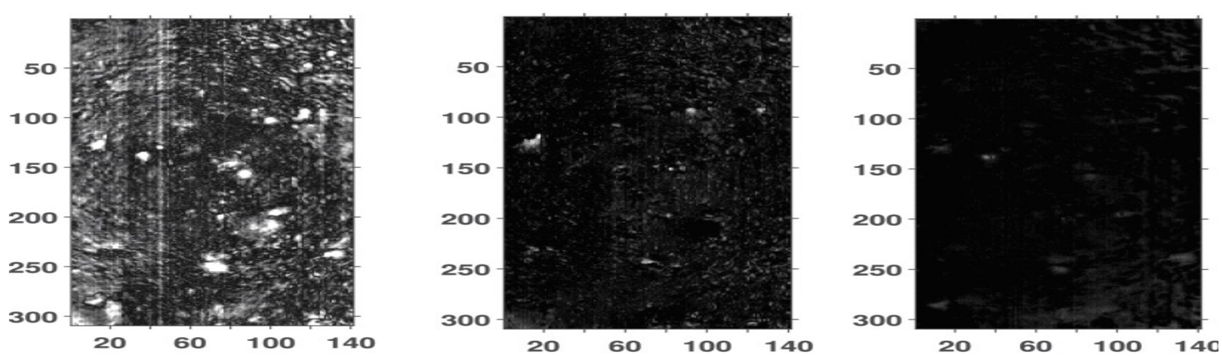
Conclusions

4.1 Results

4.1.1 Spoilage Detection and Model Training

The spoiled data in acquired samples are detected by analysing the differenced image which were calculated by subtracting every sample (Sample 2 to 16) from sample 1 to obtain the pixels that have got changed over time.Sample 1 is considered as a fresh and healthy piece of the sponge cake. The difference of samples acquired in the first four days (Sample 2 to Sample 8) didn't show any visible changes. From the fifth day, i.e, sample 9 to 12 has been used to detect the spoiled information. From sample 13 the spoilage became notable with naked eyes.Therefore, the samples from 13 to 16 were not used due to the complete spoilage of the cake.

From the experimental analysis it is obtained that PC1 (principal component 1) contains the maximum information of microbial spoilage .Therefore, PC 1 has been used for every sample in further steps.



(a) PC 1 (b) PC 2 (c) PC 3

Figure 1: First three PC's of difference image (Sample 1 - Sample 10).

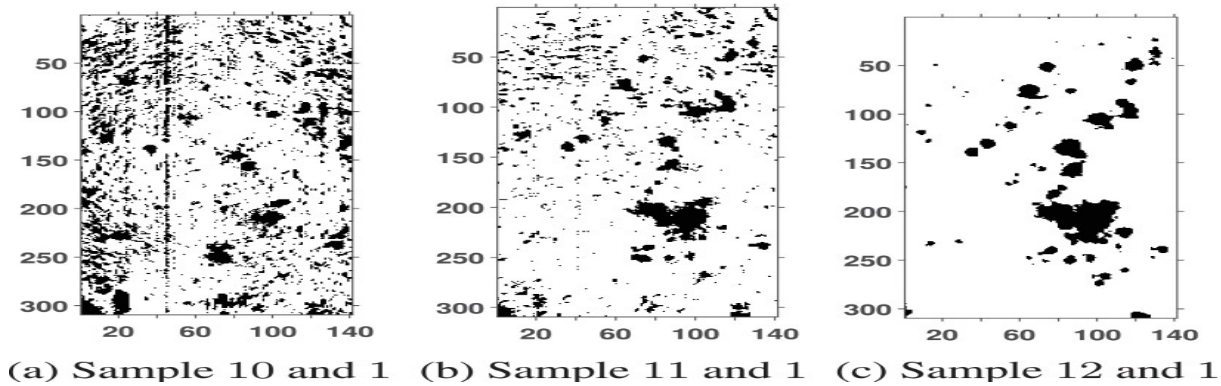


Figure 2: K-means clustering results for three Sample 10, 11,12

To divide the data into healthy and spoiled segments,K-means has been applied on PC 1.Fig.2 shows the result of applying k-mean (k = 2) on PC 1 of Sample 10 to Sample 12.

After detecting the spoiled pixels, an SVM (Support vector machine) classifier has been trained. To validate the trained model to distinguish between healthy and spoiled samples, new samples are acquired and preserved in the same environment. Similarly, new samples have been used to test whether the samples are exposed microbially to spoilage or not without considering the prior knowledge of class information i.e., spoiled or healthy.Finally, the proposed model has achieved 98.13% accuracy on test data which is measureed using confusion matrix.

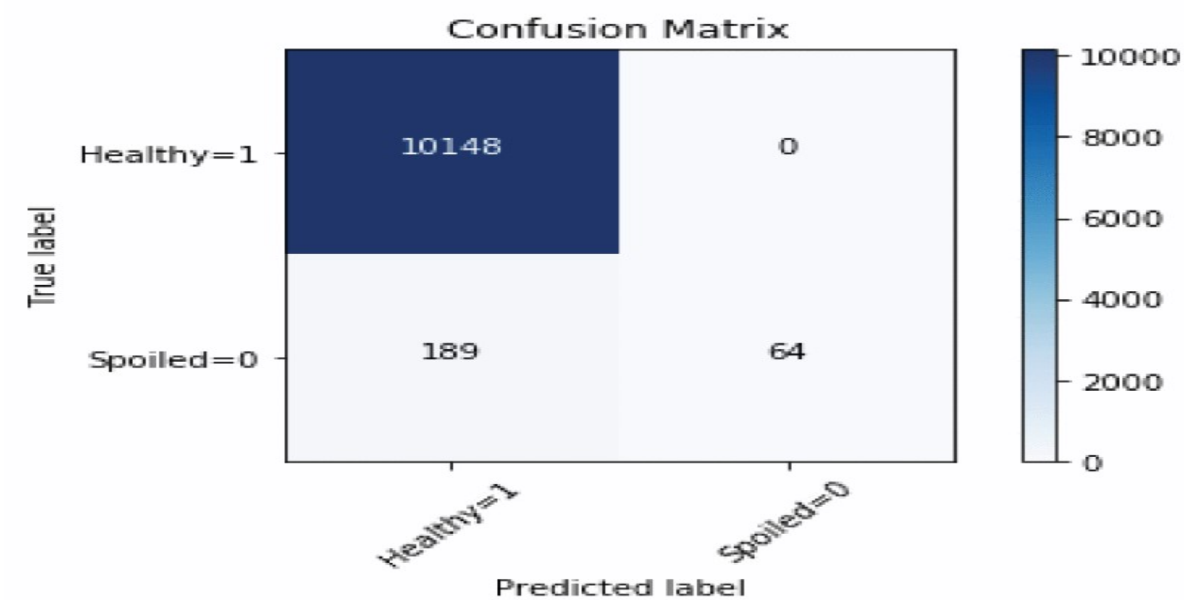


Figure 3: confusion matrix of test data

The figure 3 shows the confusion matrix obtained from the test data.A confusion matrix is a table that is often used to describe the performance of a classification model (or "classifier") on a set of test data for which the true values are known[13].Here the accuracy of the model is measured using the confusion matrix.

Figure 4 shows the final prediction result of all the samples from Sample 1 to Sample 16.

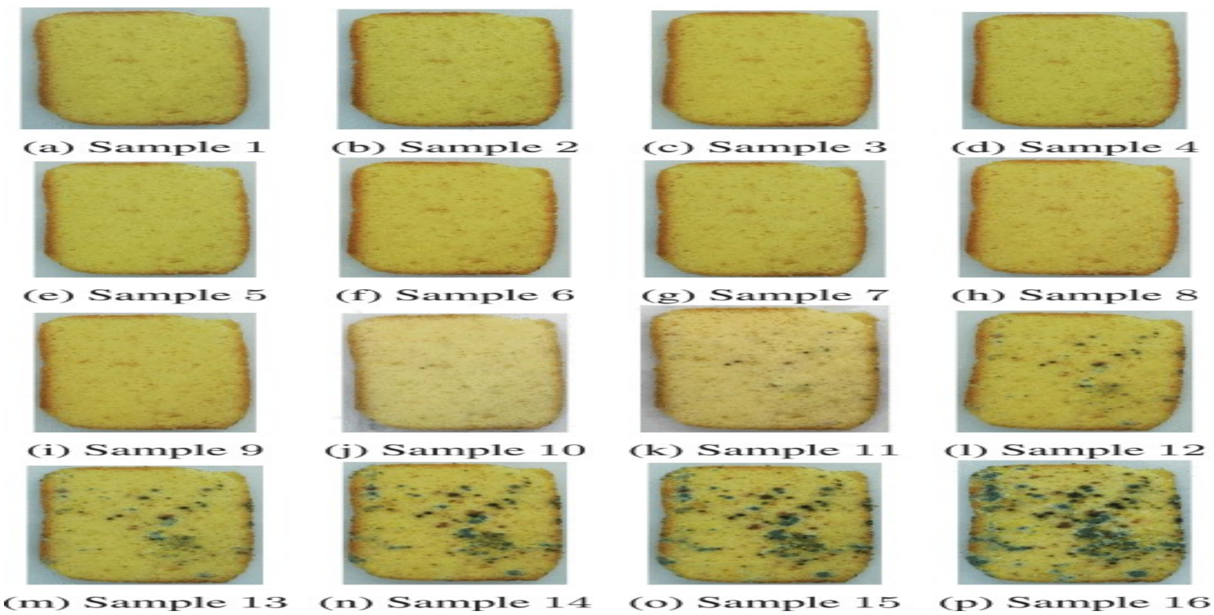


Figure 4: True color images of sample 1 to 16.

4.2 Conclusions

This approach is used to detect and predict the microbial spoilage in baked cake samples using Hyperspectral Imaging.The experimental analysis was conducted on total of 16 HSI data samples that have been acquired over the span of 8 days with a 12 hours difference in each sample.The proposed approach uses various image pre-processing techniques on hyperspectral images of acquired data samples.Then PCA followed by K-means clustering has been used on HSI differenced images to automatically detect the microbial spoilage. Finally, multi-class SVM has been trained and tested on spoiled and healthy pixels for prediction. The results revealed that the method not only automatically detected the spoilage but also predicted it a day, with 98.13% accuracy on test data, before it starts appearing visibly notable.

4.3 Future Scope

In future the hyperspectral imaging system used in this model can be improved by using Led lamps for illuminating the samples as it radiates much less heat than halogen lamps.Since,LEDs do not offer uniform illumination as they have a large peak in the blue region of the spectrum while the red components are very weak.So,inorder to provide uniform illumination for better hyperspectral imaging,broadband LEDs would be used.It could illuminate light over a broad spectrum that resembles the halogen lamps.They generate a smooth continuous spectrum across the wavelength range with a similar spectral distribution to halogen. The hyperspectral imaging technique can be also applied to smartphones makes acquisition simple without laboratory setup.The spatial resolution of hyperspectral imaging could be improved to detect smaller foreign objects such as plastic shards,glass beads etc along with microbial spoilage detection.

References

[1] Zainab Saleem, Muhammad Hussain Khan, Muhammad Ahmed Sohaib, Hamail Ayaz and Manuel Mazzara ,"Prediction of Microbial Spoilage and Shelf-Life of Bakery Products Through Hyperspectral Imaging" IEEE Access, vol.8, pp.176986 - 176996, September 2020.

[2] https://en.wikipedia.org/wiki/Hyperspectralimaging

[3] M. Ahmad, M. Mazzara, R. A. Raza, S. Distefano, M. Asif, M. S. Sarfraz, A. M. Khan, and A. Sohaib , "Multiclass non-randomized Spectral-Spatial active learning for hyperspectral image classification", Appl. Sci., vol. 10, no. 14, p. 4739, Jul. 2020

[4] D. Vakhare, A. Gupta, and S. R. Chaphalkar,"Confocal microscopy and its implementation in different biological aspects", Emergent Life Sci. Res., vol. 2, pp. 8-12, Dec. 2016.

[5] Y. Zhang, L. Zhu, P. He, and Q.Wang, "Simultaneous detection of three foodborne pathogenic bacteria in food samples by microchip capillary electrophoresis in combination with polymerase chain reaction", J. Chromatography A, vol. 1555, pp. 100-105, Jun. 2018

[6] M. Gallo, L. Ferrara, and D. Naviglio, "Application of ultrasound in food science and technology: A perspective", Foods, vol. 7, no. 10, p. 164, Oct. 2018.

[7] M. S. Andresen, B. S. Dissing, and H. Loje, "Quality assessment of butter cookies applying multispectral imaging", Food Sci. Nutrition, vol. 1, no. 4, pp. 315-323, Jul. 2013.

[8] A. Polak, F. K. Coutts, P. Murray, and S. Marshall, "Use of hyperspectral imaging for cake moisture and hardness prediction", IET Image Process., vol. 13, no. 7, pp. 1152-1160, May 2019

[9] https://en.wikipedia.org/wiki/Image-fusion

[10] Petruzzi, M. R. Corbo, M. Sinigaglia, and A. Bevilacqua, "Microbial spoilage of foods: Fundamentals", in The Microbiological Quality of Food. Amsterdam, The Netherlands: Elsevier, 2017, pp. 1-21.

[11] Y. Ait-Sahalia and D. Xiu, "Principal component analysis of highfrequency data", J. Amer. Stat. Assoc., vol. 114, no. 525, pp. 287-303, Jun. 2019.

[12] J. Lever, M. Krzywinski, and N. Altman, "Points of significance: Principal component analysis", Nature Methods, vol. 14, no. 7, pp. 641-642, Jun. 2017.

[13] https://www.dataschool.io/simple-guide-to-confusion-matrix-terminology