A Review: Milk Spoilage and Staleness Detection Approaches, Technique, and Technology Trends

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DOI: 10.29322/IJSRP.12.04.2022.p124XX
http://dx.doi.org/10.29322/IJSRP.12.04.2022.p12419

Paper Received Date: 14th March 2022
Paper Acceptance Date: 31st March 2022
Paper Publication Date: 6th April 2022

Abstract- Milk is one of the primary food nutrition consumed by almost all countries globally. The milk is commonly packed with several containers such as carton, can, glass bottle, and pet bottle. The milk, however, has limited time for the buyer to consume it, as it has an expiring date. The expired date could be unclear and uncertain as the milk could be spoiled by itself according to how we kept it after the first container was opened. To encounter the milk spoilage and staleness problems, many research works were proposed from 1949 until recent for having a sound system on detecting the milk. Since this food safety and quality is one of the crucial areas, this paper analyzes the trends and approaches towards milk spoilage and staleness detection systematically. The category of the detection system, sensor technology, ingredient technology, image processing technique, and deep learning technique will be discussed technically. The paper also provides a brief comment and idea on the existing methods conducted by the previous researcher in their work. Finally, this paper will conclude the milk spoilage and staleness detection system trends and predict what could happen in a few years facing the industrial revolution 4.0.

Index Terms- deep learning, food safety and quality, image processing, milk staleness, pH, sensors

I. INTRODUCTION

Milk provides a complete package of nutrients for the mammary glands of mammals. From the birth phase, young mammals are fed breastfed milk by the mother. Milk is a crucial liquid to the young mammal to start their first digestion as a mammal. Furthermore, the early breastfeeding phase provides necessary antibodies that could strengthen the immune system of younger mammals, including humans. Containing the colostrum, protein, and lactose will sustain mammals and humans with a healthy environment and keep an energetic rhythm for daily life activities. World Health Organization strongly advises exclusive breastfeeding for the first six months of baby, followed by continued breastfeeding with proper complementary foods for up to two years and beyond.

As additional food for the younger age of baby, cow milk has become widely consumed worldwide. To provide a consistent milk supply for the demand, since 2011, the dairy farm has produced approximately 730 million tons of milk from nearly 260 million dairy cows. Many countries, such as India, the European Union, the United States of America, Pakistan, and Brazil, are among the top rank of milk product exporters to the whole globe. Not only for the baby and kids, but an adult also consumes milk simultaneously. In total, more than six billion people around the globe consume milk and milk products in their daily life. Milk is categorized by liquid milk, fermented milk, cheeses, butter and ghee, condensed milk, evaporated milk, dry milk powder, cream, whey product, casein. Here, liquid milk is the most consumed by people. Liquid milk comprises pasteurized milk, ultra-high-temperature (UHT) milk skimmed milk, standardized milk, reconstituted milk, and fortified milk. Nevertheless, this liquid milk is less consumed in its raw form as the safety and quality aspect for keeping it stay longer for a long-used at home. As the safety and quality of the milk product are a concern, this paper reviews the all-around aspect of the milk produced by focusing on milk spoilage and staleness.

The paper will bring the earliest research work paper, 1949, which discusses milk quality in the production link to the existing bacteria surrounding the milk. Besides looking into the traditional aspect of milk production, the paper will briefly discuss several categories and approaches with the technology trends specifically in this milk production. The approaches here and the trend will be divided into some categories, making it easy to read this paper. Year of work, technology categories, and approaches will be discussed by commenting and exploring the current milk spoilage and staleness work. The paper will conclude and forecast future opportunities and expectations of the technology in the coming years by looking closely at these reviews of the milk approaches and technology trends. The paper will:

1) Prepare readers' most recent milk spoilage, and staleness for milk protection works in a holistic review that covers the majority of referred works from five years back
2) Provide various technique trends on the milk quality, especially for the end-user, everyday consumer

Figure 1: Category of Milk Spoilage and Detection

3) Predict the prospect of future pre-process, process, and post-process milk production technique changes and the future prospect.

This paper is consisted of four sections. Section 2 discusses the previous works for milk quality. Section 3 presents the reviews' results related to the approach and technology trends on milk spoilage and staleness detection. Section 4 concludes and provides the future direction of the result topic in this paper.

II. Milk Spoilage and Staleness Detection System

In producing bulk milk, especially in the factory, spoilage and staleness detection became a high demand. This system helps the milk products do early detection to keep the milk fresh in a time according to the expiry date. Pre-process, process, and post-process are simultaneously crucial in producing a good quality of milk that reaches the buyer's house. For these three different milk production processes, the paper will categorize them into several milk spoilage and staleness detection systems; pH level, sensory evaluation technique, milk ingredient related sensory technique, image processing technique, and recently deep learning techniques as illustrated in Figure 1 above.

III. Comparison on the Milk Spoilage and Staleness Detection System

This section will discuss on details about the works conducted in the five categories, pH level, sensory evaluation technique, milk ingredient related sensory technique, image processing technique, and deep learning techniques. The works are listed and discussed from the year timeline which will ease the reader to understand the trends in each of the technique.

A. pH level technique

pH is used as the idea to observe the substance either in acid, neutral or alkaline conditions. This condition allows a specific bacterium that could inhibit growth at one of the three pH conditions. Since further growth of these bacteria in milk substance, the detection differs on the bacteria type. These three conditions, acidic, neutral, and alkaline, are interdependent and include nutrient availability, moisture, oxygen levels, and other gases, the presence of inhibitors, temperature, and pH [1]. In the general case, the pH of unspoiled milk is around 6.7, where many bacteria's states succeed [2]. The relation between the pH level could indicate by looking at the existence of Coliforms, a general form of bacteria, which examined by the existence of water in milk products later could spoil the milk [3]. An example of well-known Coliforms is Escherichia Coli, promoting bacteria growth in a milk product.

Besides, the acidity could also increase milk spoiling by analyzing the milk with the total acid content and hydrogen ion concentration (pH), where these two will represent the acid strength [4].

A study that confirmed the effect of pH in milk production is carefully analyzed by Fromm and Boor, where attributes of pasteurized fluid milk are becoming their study objective [5]. In this technique, the Milkmaid jug shows an alternative for dairy milk consumers to detect milk spoilage by pouring it into their invented jug. Indirectly one of the elements in their work, Frederick Tawi Tabit, proposed a technique to evaluate the prevalence of Bacillus Sporothermodurans in UHT milk brands in South Africa. They analyzed the level of proteolysis in UHT milk due to the growth of B.sporothermodurans during short-term and long-term storage [6]. Al Usturoi et al. discussed an idea on the milk and some other dairy product quality obtained into a small production unit. Several dairy products are chosen in their study and report an improvement of 0.22% higher than the one imposed by the firm's standard [9].

B. Sensory evaluation technique

A sensor is an electronic sensor device that will react and conduct electricity if there are any responses with other equal or distinct substances. This equality and distinctly is the sensing context will trigger a specific scale of value. Discussion on sensor-related techniques for detecting the milk quality could distinguish as the physical sensor on the milk component the analysis on gas exhibited from the milk product sensor. Pablo Gutieeraz et al. wrote a research paper on developing a biosensor system. Their proposed system integrates nanotechnology, optomechanics, and a spectral detection algorithm for conducting a sensitive quantification on antibiotic residues for raw cow milk. They developed and investigated a prototype called an automatic electro-Opto-mechanic system for measuring the optical absorption response of antibiotic-specific NBS in multiple samples of clarified milk [10]. Later, Ping Yang et al. provided their idea related to a sensor technique [11]. They identified off-flavor compounds in IF-DHMP using sensory-directed analysis. In total, 56 types of aroma-active compounds were identified in the off-flavor (OF) samples, positive control (PC) samples, and accelerated oxidation (AO) samples.

Hao Zhang et al. study: reported that the sensory-directed analysis was used to examine the odor distinctions between human milk and baby formula [16]. Aroma extraction dilution analysis (AEDA) outcomes showed that carbonyl compounds and alcohols were the essential components with the higher dilution factors (FD) in human milk and infant formula using 14 key aroma active compounds. By optimizing the processing temperature and the fat composition of the raw milk to reduce the degree of milk fat oxidation and altering the proportion of the nutrients, e.g., protein and inorganic salts in the raw milk. This optimization later showed changes in the degree of odor molecules released from infant formula to improve the odors of infant formula. Notably, the overall flavor of infant formula is more robust than that of human milk.

Cadwallader Dylan et al. compared the sensory and chemical properties of fluid milk packaged in paperboard cartons, low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyethylene terephthalate (PET), linear low-density

polyethylene (LLDPE), and glass [19]. From their study, consumer differences tests were comparable with trained panel and volatile compound analysis, suggesting that HTST milks packaged in HDPE, PET, or glass without light exposure have no discernable differences by Day 10 post-processing.

C. Milk ingredient and production technique

The third technique that is categorized in this paper consisted of both, milk ingredient and milk production technique either in pre-processing, during the processing and could be post-processing. One of the earliest works on milk production was conducted by Mildred R. Wilson and Harry H. Weiser [18]. They studied the growth characteristic of one bacterium, Escherichia Coli, on dairy products. They found that the contamination value or index is less valuable if the organisms die very rapidly. Nevertheless, if this organism multiplies quickly at storage temperature, the actual degree of contamination is later may be obscured. Mohd Ajmal et al. proposed an idea on a chilling technique that will later help prevent unwanted milk. The additional unwanted ingredient could exist after some time from the production date. This investigation showed that delayed chilling of raw milk leads to several undesirable chemical changes in the lipid fraction of milk [7].

The method utilized temperature controller, motor wiper, and heat exchanger technology proposed by Yan Dwi Partama et al. soaked in water in water during the processing machine, cooling, and packing of cow milk [8]. This technique could increase double the productivity and effectiveness of the whole production process for Small and Medium Enterprise (SME) company that yields an average of one hundred liters to two hundred liters of milk daily. Riccardo Bottiroli proposed a technique which monitored the quality over time of UHLM produced “in batch” and stored at 4, 20, 30 and 40 ◦C focusing on proteolysis, volatiles organic compounds (VOCs) formation and color changes. Their work result suggested the involvement of Maillard reaction, protein, and lipid oxidation required a systematic coordinate to milk browning and off-flavors formation in UHLM [12].

Azamataufiq Budiprasojo, in his paper, concluded that the sterilization process of packaged bottles with sterilizers portable UV-C light could be one application of technology to be used in the future. The usage of UV-C will increase turnover due to digital marketing, improved quality of processed products hygienically [13]. Then, Andrew Setiawan Rusdianto proposed the development of a prototype smart label of purple sweet potato’s anthocyanin extract [14]. The proposed prototype is to determine the feasibility of a smart label on the packaging as an indicator of milk freshness. Purple sweet potato extract was obtained via the maceration method using 96% ethanol and aquadest, which was acidified with acetic acid. Their study presented the feasibility of smart labels on pH stability to indicate colour changes in acidic and alkaline conditions, but more stability is evident in acidic conditions.

A review conducted using a questionnaire by Honghao Cai revealed that protein, calcium, and fat were the essential nutrients consumers sought to obtain through drinking milk [15]. Their study also presents that multivariate linear regression analysis showed that the protein has a significant and positive impact on the price. Later, Katherine Blackshaw et al. [17] assessed the application of freeze-drying followed by low-dose gamma irradiation of DHM for simplified, safe long-term storage. Their finding through their study result showed that these methods, freeze-drying, may generate a means to create a reserve stock of DHM for emergencies and humanitarian aid. Many other works are done by research using this technique are also discussed in the review paper [20].

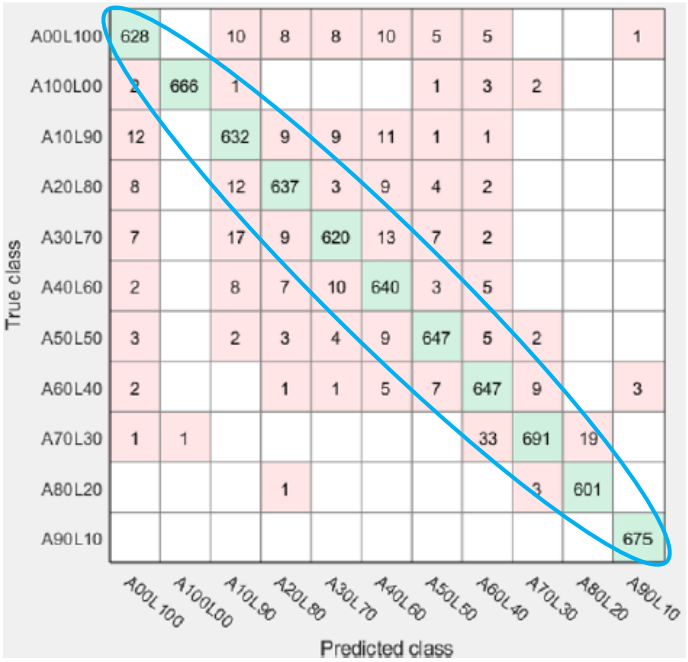

Figure 2: Confusion Matrix Generated by the Classification Learner Application [21]

D. Image processing technique

Image processing refers to transforming an image into a digital form and performing respective processes to gain helpful knowledge; in engineering, we define it as image knowledge. When applying specific predetermined signal processing methods, the image processing system treats all images as 2D signals. Alvarado-Díaz Witman et al. wrote in their technical paper about the Peru situation on milk consumption [21]. This idea produced a reduction in the costs of milk analysis. They used the Matlab Classification Learner and the fine K-Nearest Neighbors (KNN) algorithm to analyze the milk spoilage and staleness detection. 11 classes are used during the analysis to present a comparable and standout confusion Matrix via the Classification Application as presented in Figure 2 above. In their paper, the application generates an approximate success rate of 95.4% by using the proposed algorithm. In technical aspect of laboratory setting, they proposed an alternative method to detect the presence of water up to 100 ml into the milk, only via an image pointed by laser photographs which illustrated by Figure 3 below. It generates a confusion matrix that considers a good classification via a new technique with image processing in 2019.

An improvement points to consider is the efficiency and the existing proposed method. The authors mentioned that the study on whether the laser power influences the calculations performed

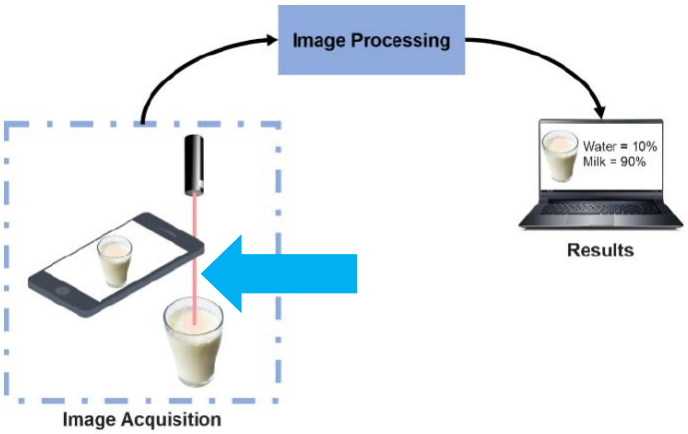

Figure 3: Image processing idea using a single laser pointed into the centered of the milk with some additional water into it [21]

should be conducted soon. They also stated that classification should also focus on milk spoilage and staleness detection via image processing technique. The remaining challenge of their paper is that it is still cannot detect adulterated milk with substances other than water. This difficulty invites a possibility of conducting studies that identify compounds other than water using a method equal or like that proposed in their work.

E. Towards Deep learning technique

Deep learning is defined as a subset of machine learning. Deep learning is a neural network with three or more layers. These designed neural networks layers later will attempt to impersonate the human brain manners. This imitation of the human brain happened after the big data and training count for making the network intelligent enough to be used in practical life activities. On the primary surface, a single layer of a neural network can yet produce inaccurate forecasts or predictions. In contrast, the additional hidden layers later can help even to optimize the classification accuracy. To the extent of our knowledge and reading, from 2016, Linear Discriminant Analysis or LDA is used in this milk spoilage and staleness detection. Anis Choiriyah conducted this work in her master's in science thesis [22].

LDA is generally used as a pre-processing step in Machine Learning and pattern classification applications. She tested the array of sensors based on the pilid membrane via the taste pattern of cow and goat milk staleness. The tasting test for cow and goat milk was done with the fresh condition till stale condition up to twelve hours. Their work found that the cow milk classification was consistently 100% for both settings, from the original data condition and the "leave-one-out" cross-validation procedure. Meanwhile, the goat milk classification was performed differently for the two settings, from the original data condition with 96.5% and for the "leave-one-out" cross-validation procedure with 94.5%. This first work via LDA with deep learning performed a promising result for opening a new door for other researchers to join into this sub-field of research [22].

Later, Imam Tazi et al. suggested a new electronic tongue using the LDA to detect taste change for bovine and goat milk in a room ambient condition [23]. The taste here is defined based on an array of lipid/polymer membranes that have been successfully developed to measure the taste evolution of natural milk. The responses of the e-tongue were evaluated using a Principal Component Analysis (PCA) and a Linear Discriminant Analysis (LDA). The advancement of the classification using LDA was obtained by adding data from a pH sensor of each measurement as 100% and 98.6% for bovine and goat milk, respectively. This work indicates that the in lab-designed e-tongue may be helpful to forecast the grade of natural milk for the food industry.

Ravinder Sign et al. in 2019 focused on the Pinni, a popular traditional milk biscuit in India using the principal component analysis (PCA). It can be observed from the axes of the three-dimensional graph that samples positioned near one of the axes has more influence on that particular PC which in turn demands concentration during technology evolution and commercialization of optimized product with desired sensory attributes. PCA identified six critical elements: shape, crumbliness, cooked flavor, color, firmness, oxidized flavor, gumminess, chewiness, cohesiveness, surface appearance, and surface coating, and moisture absorption, which governed much of the variation in the sensory scores of Pinni.

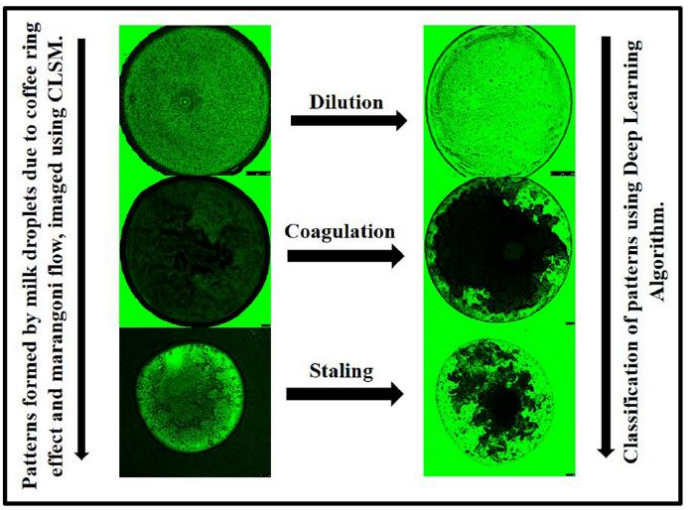

Figure 4: Example images for the dilution, coagulation, and staling. [25]

The most recent work which closely related to deep learning is by Aswini Harindran et al. in 2021. The most recent work closely related to deep learning is by Aswini Harindran et al. in 2021. They proposed two methods, one traditional experimental setting and the other based on an artificial deep learning approach. Their research paper explored the potential of identifying adulteration, coagulation, and spoilage of dairy milk as in Figure 4 above. Dairy milk colloids are generally formed in several unique patterns under dilution, coagulation, and staling conditions. The experimental work was done by observation using confocal laser scanning microscopy. Each pattern obtained in the experimental result is unique, and therefore these can be utilized to fingerprint the state of milk colloids. The algorithm employed successfully classified the images into the three

categories, and the prediction precision of the trained network is about 85%.

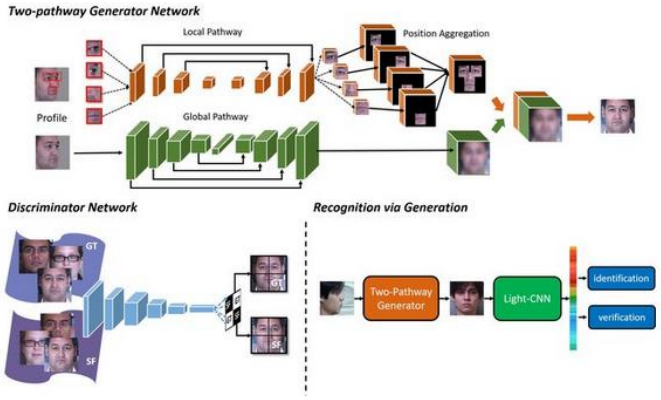

Figure 5: General framework of TP-GAN. The Generator contains two pathways with each processing global or local transformations [26]

IV. Review Results

The trends of approaches, methods, and technology used could be finalized from the five listed categories of the milk spoilage and staleness detection system. From the pH level analysis, the detection of the milk was happened by choosing the milk condition, either acidic, neutral, or alkaline. Apart from the milk condition, bacterium and viruses exist also one factor in inferring the pH level in the milk substance. Meanwhile, the milk type process could also be considered a discussion topic here, as the milk is processed by pasteurized or UHT method.

Although most of the work widely focused on sensor techniques, this technique could be performed hybrid with the newcomers, statistical analysis, or deep learning approaches. The milk ingredient sensory and production technique, on the other hand, was the main focus among the majority of the researchers, could be simultaneously implemented with the touch of the Internet of Things (IoT) and the use of the recent controller, which is economical for the milk production.

The image processing technique and the deep learning approach are expected to be the dominant research technique for prospective prospects. However, this requires a massive amount of data or images readily available to be gained by other researchers worldwide. Though the existing milk dataset images are still relatively small, this could cater to the utilization of the Generative Adversarial Networks (GANs) for expanding the existing dataset image as illustrated in Figure 5 above. The researcher is facing difficulty in finding these images. The image patches could also be possibly implemented in finding the unique part of the milk image to gain a specific region of interest during the deep learning technique analysis as presented in Figure 6. Furthermore, a new idea on describing the milk as a feature before embedding the image into any convolution is an alternative to getting a reliable network model.

V. Conclusions

From the review conducted with the listed previous work in milk spoilage and detection system, it is expected that there is a potential for expanding the image processing technique to do

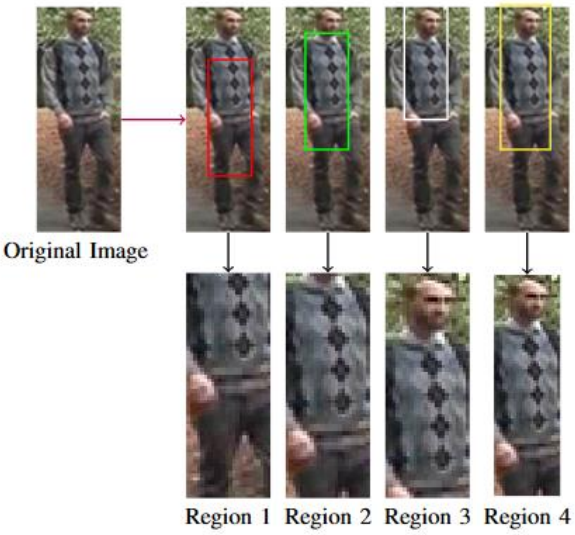

Figure 6: Example of image cropping with four different positions as image patches [27] for a person image in a person re-identification task using VIPER dataset images [28]

this task. The limitation of the image processing approaches used in this aspect invites a vast opportunity to detect the using manipulation or upgrade the existing technology to improve the detection in the future. Still, the metric learning, feature implementation, bag or words (BoW), or many more ideas could also vary a good result after a systematic analysis of milk production. Furthermore, the role of an intelligent computer brain using the deep learning approach could also infer a new milk image paradigm to detect spoilage and staleness. For this reason, there is a crucial demand for completing and introducing a ready, comprehensive, and systematic dataset consisting of the various image and milk condition settings through positive and negative factors related to the milk ingredient.

Acknowledgment

The authors would like to thank Jabatan Kesihatan Negeri Perak, Bahagian Keselematan dan Kualiti Makanan, Kementerian Kesihatan Malaysia and Kolej Komuniti Segamat 2 for the Research Project Collaboration with Universiti Teknikal Malaysia Melaka during many discussion and research activities conducted together in both facilities.

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