

# AI-ENHANCED SPECKLE PATTERN IMAGING FOR ASSESSING MILK AUTHENTICITY

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**Abstract** Milk is daily consumed worldwide by billions of people and it is also one of the food most commonly subject to adulteration and counterfeiting. This paper presents a novel low-cost approach to assess milk authenticity by combining speckle pattern imaging and artificial intelligence. From the collected images, 11 statistical parameters were extracted and used to train and test a machine learning model, with the aim of distinguishing whole cow milk and 8 adulterated samples. The performances achieved by the AI-enhanced speckle pattern imaging approach (accuracy of 80%) represent a promising starting point for the development of this label free, low-cost, easy-to-use technique to support efforts in fighting food fraud.

**Keywords:** Artificial Intelligence, Food Safety, Milk Adulteration, Optoelectronic Instrumentation, Speckle Pattern Imaging

## 1. INTRODUCTION

According to the United Nations, world population is expected to reach 9.8 billion in 2050. In this context, ensuring safety and sustainability of widely consumed foods such as milk represents a big challenge. In particular, according to the Food Fraud Summary Reports released every month by the European Commission, milk is one of the products most frequently prone to adulteration and food fraud [1]. State-of-the-art methods for analysis of milk adulterants are mainly based on cryoscopy, mass spectrometry, NIR/MIR spectroscopy and chemical tests. Although highly sensitive and specific, these techniques have significant drawbacks: they are expensive and complex and require dedicated laboratories and long sample treatment time [2,3].

Within this scenario, this research introduces an artificial intelligence (AI)-enhanced optical sensing approach to analyze milk samples, study their authenticity and detect possible adulteration. Our methodology integrates speckle pattern (SP) imaging [4] and machine learning (ML) in an innovative manner [5] to investigate milk, which generates diffused light since it is an emulsion composed of a liquid matrix with lipid globules and casein micelles acting as suspended particles. In more detail, generated SPs are rich in information about milk samples that generate them, which can be represented by means of specific statistical features that can be extracted from the images and then properly elaborated using ML algorithms. Our analysis platform is label-free, contactless, low-cost and easy-to-use, potentially representing a valid alternative to traditional testing methods.

## 2. METHODS AND PROCEDURES

The low-cost intuitive-to-use optoelectronic configuration implemented to generate and collect SP images

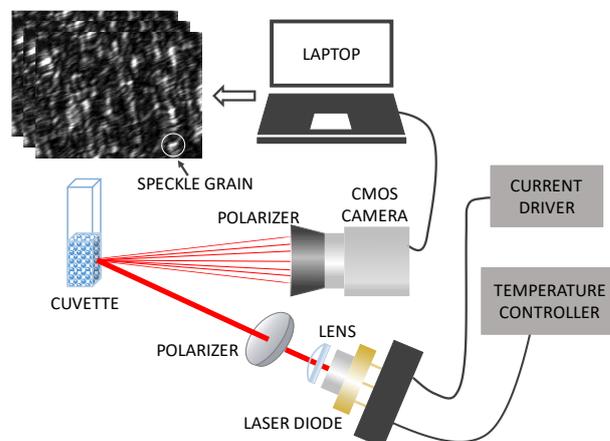


Figure 1. Schematic of the optoelectronic configuration developed to irradiate milk samples with a low-cost laser diode and to collect SP images with an industrial CMOS camera.

is reported in Figure 1. It consists of a low-power red laser diode (L658P040, Thorlabs, NJ, USA) powered by a bench driver ( $P_{\text{laser}} \approx 30$  mW) and stabilized in temperature ( $T_{\text{laser}} = 25$  °C), a lens (C230260P-B, Thorlabs, NJ, USA) to focus light of the sample, two film polarizers (LPVISE100-A, Thorlabs, NJ, USA) and a monochromatic CMOS camera (Alvium 1800 U-158m, Allied Vision, Germany). Milk samples are contained in plastic disposable cuvettes: coherent light reaches the fluid and it is back diffused. Scattered rays interact generating an interference pattern that is time variant, since particles in milk are subject to Brownian motion. Sequences of SP images are then acquired by means of a laptop USB-connected with the camera using an exposure time of 600  $\mu$ s and a frame rate of 90 fps.

Starting from a batch of whole cow milk (containing 36 g/L of lipids) purchased at a local store, we prepared 8 adulterated samples containing 90%, 80%, 70%, and 60% of whole milk adulterated with the remaining percentage (10%, 20%, 30%, and 40%) of either water (4 samples) or a glucose-water syrup with 12.5% glucose concentration (4 samples), being the most common adulterants added to milk.

Video sequences constituted of 100 SP frames were collected with 8-bit depth (gray level from 0 to 255) for each sample and the measurement was repeated three times (300 images in total). From every image, we extracted 7 statistical parameters: mean intensity, median intensity, standard deviation, skewness and kurtosis of gray level intensity, contrast, and grain dimension along x-dimension and y-dimension. Moreover, from every SP images we computed the Gray-Level Co-Occurrence Matrix (GLCM) [6], representing the distribution of co-occurring pixel values in a given direction, and we then extracted 4 more parameters (GLCM correlation, GLCM contrast, GLCM energy, and GLCM homogeneity).

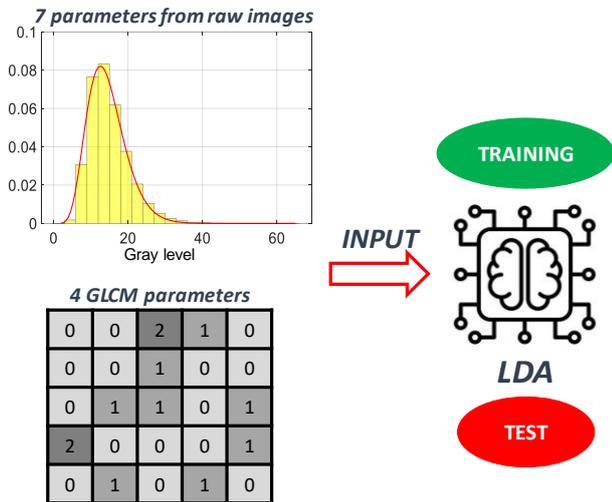


Figure 2. 7 statistical parameters extracted from raw SP images and 4 statistical features extracted from the GLCM matrix were used as input data of a SVM model.

### 3. RESULTS AND DISCUSSION

Using the measuring configuration of Figure 1, we tested whole milk and the 8 adulterated milk samples: from every SP image we then extracted the 11 statistical parameters previously described. We thus obtained a dataset composed of 2.700 instances (300 images  $\times$  9 samples) and 12 columns (1 label and 11 statistical features). Eventually, we partitioned our dataset into training (~67%) and test (~33%) sets, by assigning to the test set one out of three independent measurements (each consisting of 100 frames) for each sample. A Linear Discriminant Analysis (LDA) model was trained and tested on collected data. The followed pipeline is schematized in Figure 2. We obtained an average accuracy on the test set of 80%, as shown by the confusion matrix of Figure 3. It also must be observed that whole milk is correctly recognized in most cases (True Positive Rate TRR = 87.9%). Furthermore, only milk adulterated with 10% of water is often misclassified as non-adulterated whole milk (42 times), while more serious adulterations (milk diluted with higher water volume or with water-glucose) are never labelled by the model as whole cow milk. This result is relevant, indicating that our approach is robust in misclassifying adulterated samples as whole milk: hence, the user can be confident that dilutions with water percentage equal or greater than 20% or with glucose-water are not indicated as healthy milk.

### 4. CONCLUSIONS

In this work, we have presented preliminary yet meaningful results about the application of an innovative AI-enhanced SP imaging measuring system for assessment of milk authenticity. The preliminary yet meaningful results obtained proved that water and glucose adulterations of cow milk can be detected with high average accuracy (80%). Our detection technique, based on a simple optoelectronic configuration, paves the way to a novel concept for milk testing. While, reference methods to analyze milk are

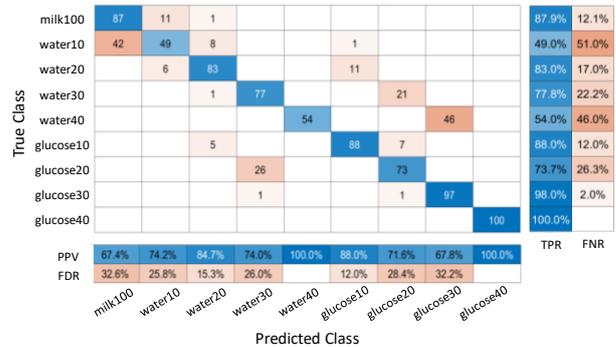


Figure 3. Confusion matrix of the test set, obtained by applying a LDA model, also reporting True Positive Rate (TPR), False Negative Rate (FNR), Predictive Positive Value (PPV) and False Discovery rate (FDR).

complex, money- and time-consuming, require dedicated laboratories and qualified technicians, by contrast, our approach is low-cost, easy-to-use also by non-qualified personnel and potentially portable for application in stables and milk production sites. Further research will focus on optimizing the optoelectronic setup, addressing sample variability across brands or producers, and testing other common adulterants, such as urea, whey and melamine.

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