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Fast, versatile, and non-destructive biscuit inspection system using spectral imaging

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Abstract

A fast, versatile, and non-destructive method for assessing biscuit quality is presented. The method integrates color (or browning) measurement, moisture assessment, compositional and dimensional measurements on a spectral imaging platform using the silicon range 400-1000 nm.

1. Introduction

In the quality control function of biscuit production a number of product properties are important to optimize production processes and to assure quality of the final product. After leaving the baking oven, the biscuits are delivered to the cooling conveyor. At the end of the cooling conveyor, a number of important quality parameters may be determined:

1. Biscuit moisture percent (%Moisture). Important parameter for texture and storability of biscuits. This is the main focus of this paper and a quantitative model is built and assessed.
2. Biscuit color or browning. Important parameter for visual quality, taste, and perhaps even for occurrence of process induced toxins like acrylamide. The measument of this parameter is shown qualitatively.
3. Coating and glazing. Parameters for visual quality, taste, and texture. The measument of this parameter is shown qualitatively.
4. Distribution of added components like chocolate chips or quinoa. This parameter is illustrated, but a solution is outside the scope of this paper.
5. Dimensional measurements like height, width, and length. These are important parameters for packaging of biscuits i.e. in determining packability. This parameter is illustrated, but a solution is outside the scope of this paper.

Based on the quality parameters above, then quality of the final product can be assured, and process parameters (like oven conveyor speed) and maintenance may be optimized.

A number of methods exist that can measure one or more of the parameters in-line, on-line, at-line or in the lab.

%Moisture is the weight of water in a biscuit as a percent of the total weight of the biscuit. In the lab it is typically measured using an evaporation device that measures the weight of a homogenized sample before and after drying. %Moisture is then the weight loss as a percent of the initial weight. The evaporation method is slow and laborious, and it has a longer lead-time to corrective actions. In contrast to this in-line measurements of %Moisture are typically based on NIR reflectance, see e.g. [4]. The NIR calibrations will be sensitive to the numerous patterns on the biscuit and to non-homogeneity in moisture distribution.

Color is typically measured in-line or in the lab by colorimeters or spectrophotometers. However, these non-imaging devices will be influenced by shape, topography, and color variations. Further, the individual parts of the biscuit – corners, edges, holes, center - will generally have differences in the desired color.

Coating and glazing are new types of measurements that some biscuit producers would like to add.

Distribution of chocolate chips, quinoa, or other added components would typically be done manually or by machine vision.

Dimensional measurements are typically done by ruler or using conventional machine vision (length, width, and shape) and laser range devices (height).

The two major advantages that spectral imaging could provide for biscuit quality assurance is

1. Versatility. Spectral imaging potentially measures all the relevant parameters in the same instrument at the same time.
2. Heterogeneity. Spectral imaging can deal effectively with the heterogeneity of the individual biscuits (edges, corners, interior, indentions, holes) as well as the variety of biscuit shapes in a normal biscuit product range.

The present paper presents one way to exploit these advantages. Only for %Moisture a quantitative comparison to conventional methods is made because this is the measurement that to the highest degree differentiates spectral imaging from conventional imaging. We have focused on spectral imaging in the silicon range in order to have a cost-efficient solution using high-resolution commodity sensors in industrial feasibility. A solution utilizing the 1000-2000 nm range will exploit more prominent water absorption peaks with a clear trade-off on cost-efficiency, resolution, and industrial feasibility.

2. Materials and methods

The imaging system used in this study, VideometerLab 2 [1], captures 18 spectral images in the range 400-1000 nm. Each band is 2 Mpixels. Acquisition is band-sequential and performed by LED strobing into an integrating sphere illumination geometry [2]. The spectral image will contain a reflectance spectrum in every pixel. This reflectance spectrum is calibrated to absolute reflectance over the full wavelength range. Acquisition and analysis is done within a few seconds. In Figure 1 we see a sample image from the instrument that illustrates the potential for measuring moisture within the spectral range that can be imaged by a standard silicon camera.

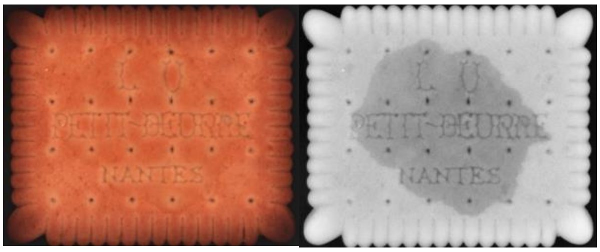

Figure 1. Left: Biscuit with water drop diffused from the center, shown as sRGB picture. Right: Same biscuit with spectrally extracted water absorption map utilizing the wavelengths around the water absorption peak at 970 nm. Image courtesy by www.videometer.com .

2.1 %Moisture model

Figure 1 is for illustration only since the moisture in this image is much higher than the relevant range for biscuit moisture, which is 1-3 %Moisture. Spectral imaging has previously been used to measure moisture in different materials e.g. sand and stones [3], and butter cookies [5]. In this study, we have taken rectangular biscuits directly from 2 production lines, on two different days. Some biscuits were measured immediately in warm condition, and some were allowed to cool off to room temperature in the lab environment. The biscuits were first imaged with VideometerLab and then 5 biscuits were grinded together and %Moisture was measured in an evaporation device. The %Moisture model was made by the following procedure

1. The exact biscuit pose is found: position and rotation.
2. Two regions are defined: an edge region consisting of pixels less than 5 mm from the outer edge, and an interior region consisting of the other pixels.
3. Indentions and holes are excluded from the above regions by using a mold-specific mask.
4. Average reflectance and standard deviation of reflectance is computed for each wavelength in each region. This provides 72 features per biscuit.
5. A linear regression using stepwise feature selection/elimination is used to model and predict %Moisture

2.2 Color and browning index model

Biscuit color is estimated either in CIELAB coordinates, or as a browning index. Both representations may be estimated in both the biscuit center region and in the edge/corner region. CIELAB coordinates are spectrally reconstructed from the reflectance spectra, the photometric XYZ distributions, and the illumination spectrum (D65 has been chosen here for CIELAB as well as for the sRGB images used in figures). The browning index is constructed using a normalized canonical discriminant analysis that optimally separates areas with no or low browning from areas with high browning. Training is done by painting training sets in selected images.

2.3 Coating and glazing model

The coating and glazing indices are constructed using a normalized canonical discriminant analysis. Training is done by painting training sets in selected images of e.g. glazed and unglazed areas.

2.4 Distribution of components

Components in the biscuit are segmented based on normalized canonical discriminant analysis. Count/Area, size, distribution, and the histogram of the Euclidean distance transformation in the biscuit background are used to assess amount and distribution of each component.

2.5 Dimensional measurements

Dimensional measurements relates to the packaging of the biscuits and consist of height and lateral dimensions, e.g. length and width, and height. Lateral dimensions are computed by fitting a template shape over the individual biscuit and measuring size and deviations in relation to the fitted template. Height measurement is done by a laser triangulation strobe.

3. Results and discussion

3.1 %Moisture model

A total of 340 biscuits were imaged, and 68 moisture evaporation measurements were done corresponding to one per five biscuits.

A biscuit moisture model has been built by least squares linear regression with stepwise selection of features with evaporation %Moisture as the ground truth even though it is known to have some variability. 8 features were selected out of the 72 original features, and they originated from both the edge/corner zone and the interior zone.

Figure 2 illustrates how two of the extreme biscuits look in sRGB (D65). The top biscuit represents the high moisture end of the population with 2.59% moisture, and the bottom biscuit represents the low moisture end with 0.89% moisture. Although there may be visual indicators of high and low moisture in these images then this information will be overlaid with a more prominent effect from the browning which will make a model based on the visible wavelengths less performing. Figure 1 illustrates clearly that using several NIR wavelengths in the range 800-1000 nm provides a clear spectral fingerprint for water (moisture) that is uninfluenced by browning. Scaled properly the reflectance at 970 nm alone – as shown in figure 3 – show a lower reflectance with higher moisture, but to get the optimal contrast and robustness regarding other disturbing effects like topography, gloss and browning then a true multi-spectral combination will do this using either e.g. canonical discriminant analysis (CDA), principal component analysis (PCA), or minimum noise fractions (MNF)

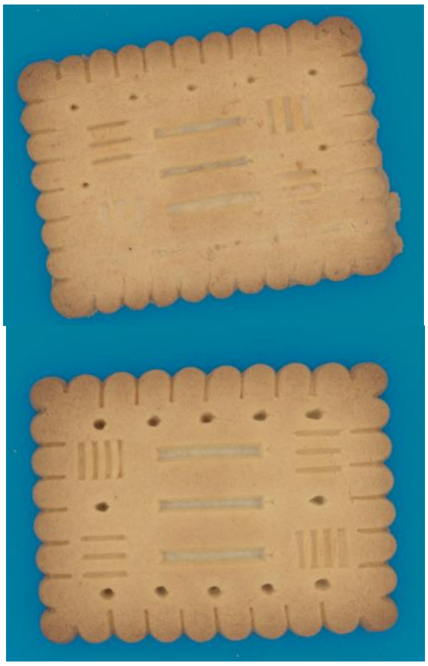

Figure 2. sRGB (D65) images of extreme examples from the data set. Top biscuit has moisture of 2.59% and bottom biscuit has moisture of 0,89%.

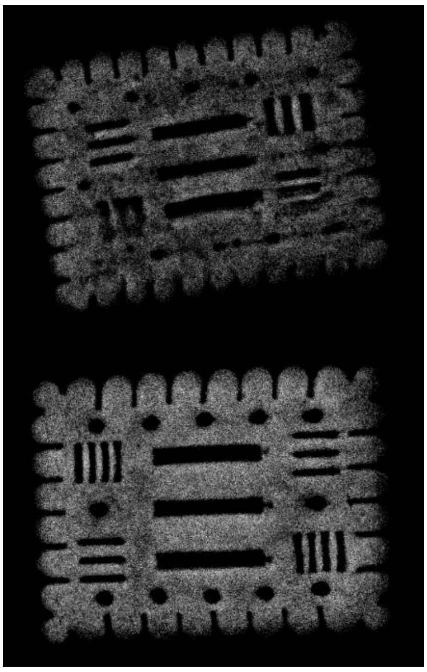

Figure 3. Reflectance at the 970 nm NIR band which is a peak in the water absorption spectrum. Image of the same two extreme examples from figure 2. Top biscuit has moisture of 2.59% and bottom biscuit has moisture of 0,89%.

Figure 4 shows the result when 50% of the biscuits is used for training and 50% is used as the test set. The prediction error RMSEP is 0.14 %Moisture on both the training and the test set. This should be compared to the result in [5] where a RMSEP of 0.22% was achieved. The better performance for biscuits could be due to the lower thickness of the biscuit compared to butter cookies and thus a higher correlation between moisture as seen from the surface and the total moisture inside the product.

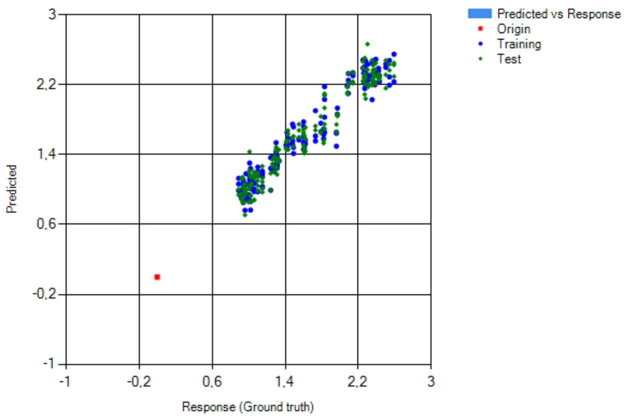

Figure 4. Predicted %Moisture from 8 spectral image features versus the %Moisture from evaporation device.

3.2 Color and browning index model

Biscuit color is estimated either in CIELAB coordinates, or as a browning index. Here we will illustrate the generation of a browning index. Figure 5 shows a simple example of how a browning index can be trained by painting representative areas and then using a normalized canonical discriminant analysis to compute the browning in every pixel.

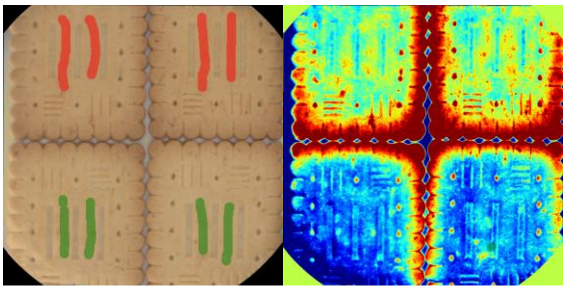

Figure 5. Four biscuits illustrating the building of a browning index. Left: Conforming interior areas are painted green, and non-conforming are painted red on a a representative set of samples. Right: Normalized canonical discriminant analysis image representing the browning index. Bluish color means conforming interior and yellow/red means a higher browning.

3.3 Coating and glazing model

The coating and glazing indices are constructed - similarly to the browning index - using a normalized canonical discriminant analysis. Training is done by painting training sets in selected images of e.g. glazed and unglazed areas. This is illustrated in figure 6.

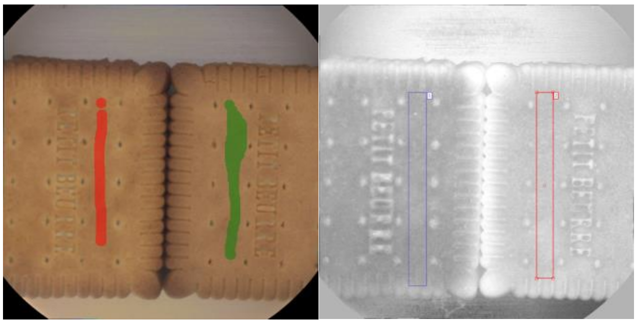

Figure 6. Left: A glazed biscuit lying on the left side of an un-glazed biscuit. Red and green color are painted training regions. Right: the canonical discriminant score image showing darker gray for glazing, and lighter gray for non-glazing.

Figure 7. Example with a glazed biscuit with chocolate chips and quinoa lying on the left side of an un-glazed biscuit with the same components.

3.4 Distribution of components

Separating components like quinoa and chocolate chips (figure 7) from other more global effects like browning, glazing, and moisture are obvious tasks for spectral image analysis. This is mostly easier than separating the global effects due to high local concentration and higher spectral specificity.

3.5 Dimensional measurements

Dimensional measurements are more standard machine vision and will not be dealt with in detail here. One challenge is the detailed definition of the dimensions as illustrated in Figure 8. How is biscuit edge to be defined? Since the goal is to assess packability then we choose to not measure flakes. Only standard features of the biscuit that is consistent with the mold are measured.

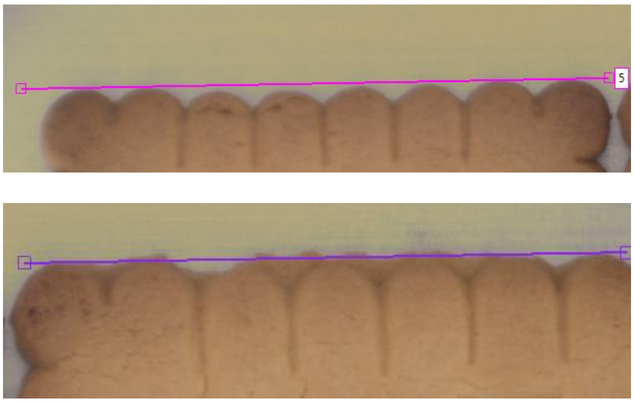

Figure 8. Definition of biscuit edge for width and length measurement used for packability. Flakes are not counted. Standard shape features are.

4. Conclusion

We have described a fast, non-destructive, versatile technique to measure a wide range of relevant biscuit quality features simultaneously. The technique can directly be placed at-line or in the lab. Alternatively, specially designed in-line systems may provide complete inspection of the final products.

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