Streamlining QC in food, feed and pharmaceuticals using Rapid Multispectral Imaging

Rapid Multispectral Imaging (RMSI) is an emerging technique developed to ensure the quality and safety of food, feed and pharmaceutical materials. Parameters measureable by multispectral imaging such as colour, texture, gloss, shape and size give useful quality information on both raw materials and finished products. Multispectral imaging provides a rapid quality assessment of uniform and inhomogeneous samples alike by combining information on all of the above parameters automatically in just a few seconds, requiring no sample preparation and leaving the sample intact.

Currently, the non-destructive investigation of materials with non-uniform colour and texture can be difficult, tedious and expensive. Conventional techniques such as NIR spectroscopy only measure a single point or average over a fixed area and do not give an objective overall assessment of visual quality. Traditional colour imaging uses three broad bands of colour: red, green and blue, and is known as RGB imaging; but as a consequence of the broad bands RGB imaging has very limited spectral resolution and is therefore unsuited to differentiating samples showing variation within a single broad band. RMSI uses narrow bandwidths (typically up to 20) over a wide spectral range from the UV through the visible to the NIR. In contrast with hyperspectral imaging, RMSI is a balance between spectral and spatial resolution, and by lowering the spectral resolution the increase in spatial information provided gives a 'snapshot' of the combined bulk properties of a sample, handling natural variation and inhomogeneity.

The earliest applications for multispectral imaging focussed in the food industry as replacements for subjective and expensive sensory panels. As these applications have become more widespread, other highly regulated industries such as pharmaceuticals have begun to reap the benefits from multispectral imaging in ensuring high quality products, and in the battle against counterfeiters. Ashort selection of applications relating to quality issues in food and animal feed production and in pharmaceutical manufacturing are discussed below to highlight the benefits of RMSI.

VideometerLab 2 is a lab based multispectral imager from the Danish based company Videometer A/S. The system is based on a high-intensity integrating sphere illumination featuring light emitting diodes (230 – 1050 nm) and a black and white high resolution CCD camera (2056 x 2056 pixels) (Figures 1 and 2). Measurements are combined at up to 20 different wavelengths into a single high resolution multispectral (2056 x 2056 x20) image with every pixel in the image representing a spectrum.

Figure 1: VideometerLab2: Up to 20 wavelengths via LEDs, uniformly spaced around the inside of the integrating sphere are strobed successively each generating a monochrome image.

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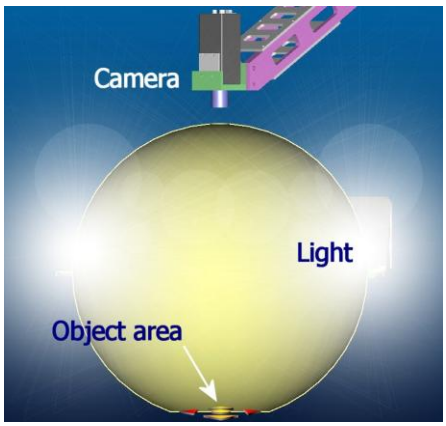

Figure 2: Schematic of integrating sphere: Internal reflection of the LEDs by the diffuse white inner surface of the sphere ensures diffuse homogeneous light for increased reproducibility, dynamic range, low scatter and shadow effects.

The choice of illumination wavelength ensures each application can be optimised and is not restricted to the wavelengths spanned by traditional RGB technology. Using LEDs in the UV or NIR adds information not visible to the human eye. As an example, most objects are white or transparent in the NIR region, which allows for the separation of the colour and surface properties of the measured object. Uniform and non-uniform samples alike are simply placed in the target area and custom designed PC software for data capture and analysis means results are available in less than 10 seconds; including sample handling time. A radiometric and geometric calibration procedure with NIST traceable standards is available to ensure accuracy and repeatability, and automatic diagnostic tests can be performed routinely to ensure instrument stability.

Visual Integrity and Material Safety

Within the QC environment there are a number of possible visual analyses of raw materials and finished products including:

- Uniform colour
- Absence of damaged material
- Particle distribution

Checks of visual integrity may currently be performed by well trained operators and are costly and subjective. An alternative is to use RMSI for a simple but objective analysis. Typically no sample preparation is needed, samples are analysed 'as is' and after placing a sample on the instrument, typically in a petri dish or similar, no further operator intervention is required. A number of quality control applications for food and feedstuffs by RMSI are shown below.

Moisture Detection in Foodstuffs

Controlling moisture in processed foodstuffs is extremely important in routine QC as the texture, stability and shelf life of a product can be affected as well as the obvious impact on taste and appearance. There are many different ways to measure moisture in finished product both in the lab and on-line, however, multispectral imaging allows immediate detection of moisture, pin-pointing areas of localised high moisture caused by defect raw materials or processes for more effective troubleshooting. Since water is strongly absorbed in the NIR region moisture detection of wet spots

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on biscuits is a simple way to demonstrate the capabilities of multispectral imaging. Figure 3 shows a single biscuit as a typical RGB image on the left and as a pseudo image where statistical translations of the differences at each wavelength are combined in a single image. High moisture is immediately apparent as the area of yellow/red shown in the pseudo image, this sample was known to contain a wet spot and no calibration for moisture was required to detect it.

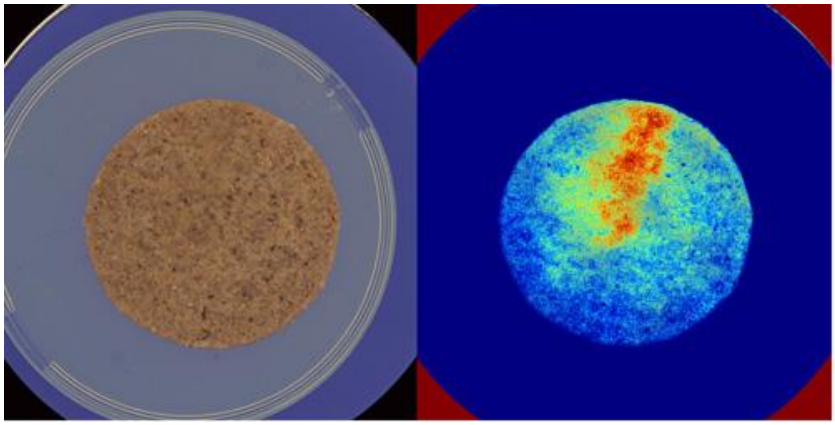

Figure 3: Biscuit moisture detection; RGB image left, pseudo image right.

Burning can be detected just as easily, 4 biscuits are shown below, only one shows signs of being burned during production. Plotting the response of the VideometerLab 2 to each of 18 LEDs (from 400 to 1000 nm) shows the three in-specification biscuits have a similar spectrum whereas the burned biscuit can be easily identified. (Figure 4).

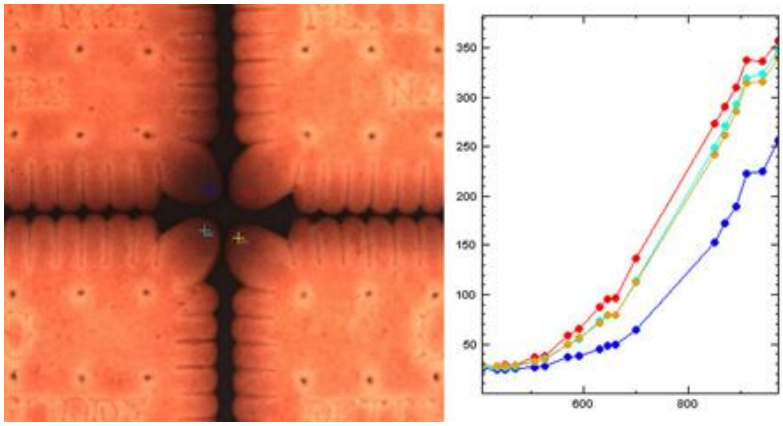

Figure 4: Biscuit burning:
Left: RGB image of four biscuits Right: Videometer output 400 -1000 nm

The appearance of biscuits can be measured objectively by simply identifying an area of 'goldening' against an area without this effect. Any further areas showing goldening will then simply be highlighted automatically. This is done using canonical discrimination; a statistical technique to maximise class separation based on between and within class covariance - this separation of 'with' and 'without' can be seen in the blue and red histograms below. (Figure 5).

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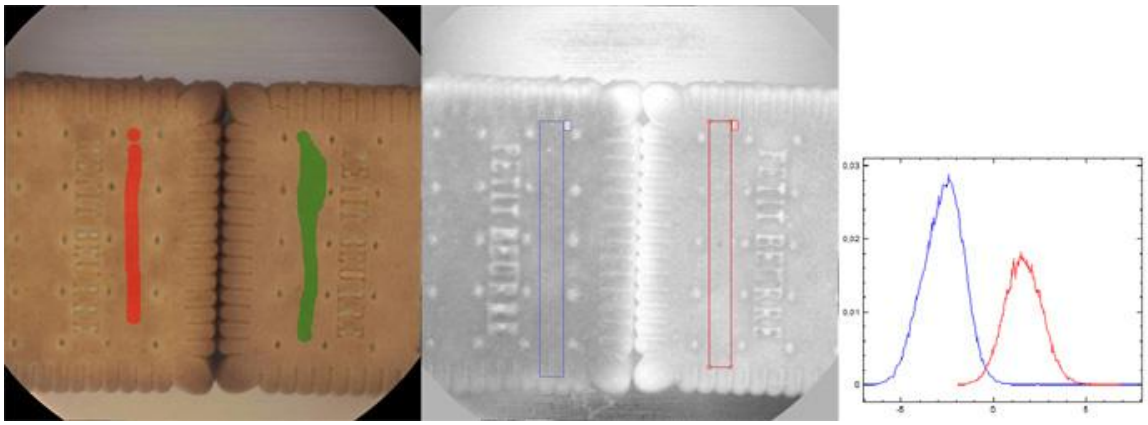

Figure 5: Biscuit goldening:
RGB image (left) showing manual selection of 'with' and 'without' goldening effect.
Pseudo image (centre)
Resultant canonical discriminant factors (right)

Analysis of Grains and Seeds

Fusarium is a fungus found in crops and soil, and although mostly harmless, some species associated with cereal crops are not. Late rain can cause Fusarium in barley, causing the harvest to rot, ultimately having a devastating effect on the brewing and malting industry, and as a result, the highest quality control standards for barley are required. A Fusarium calibration for barley was developed in collaboration with Carlsberg Research Center (CRC) and the Danish Malting Group. The calibration is based on an extensive set of barley samples with different levels of Fusarium infection and several barley cultivars, collected from all over the world, are represented. The degree of Fusarium infection is shown directly in a pseudo-colour image – with orange/red areas indicating the degree of infection. Figure 6. Together with the pseudo-coloured image the infection is also calculated as the relative area of infection. Validation by CRC gave an excellent correlation to real-time PCR (R^2=0.85). Fusarium in wheat and maize crops can be analysed in a similar manner.

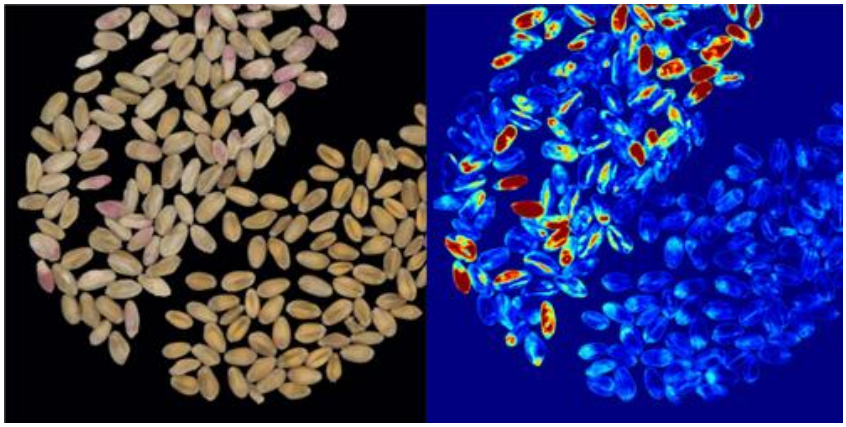

Figure 6: Fusarium in Barley: RGB image (left) and pseudo image.
Fusarium infected barley clearly differentiated in red

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There are many other applications of multispectral imaging for the automatic screening and analysis of grain/seeds as shown in table 1: Automatic seed sorting by size, shape, colour and translucency is shown visually in figure 7. RMSI can therefore be used to automatically identify wheat variety.

Plant breeding	Screening, product appraisal
Seed technology	Seed coating, pelleting, seed borne diseases
Sowing	Germination, high value seed selection
Cleaning	Purity, broken grains
Refining	Milling, pelleting, mixing
Malting	Degree of hydration, chitting, rootlets, acrospire length

Table 1: Grain / seed applications for RMSI

Figure 7: Automatic seed sorting

Meat Analysis

There are many applications of multispectral imaging in the meat processing industry. A quality control application with an almost immediate return on investment is to predict when a whole batch of processed meat will begin to discolour and be less attractive to a consumer making the purchase. Such produce can be discounted for quick sale. Oxygen carrying/storing muscle pigments found in meat vary in colour, the VideometerLab 2 was used to conduct a minced beef spoilage study comparing the colour of product stored under different conditions (5degC, normal atmosphere or with modified atmosphere packaging (MAP)). Changes in colour and surface chemistry associated with meat spoilage were monitored by the application of a canonical discriminant function. Results showed aerobic storage gave its greatest colour change from 50 to 90 hours storage whereas MAP storage gave a smaller but significant and unimodal colour change. (Figure 8).

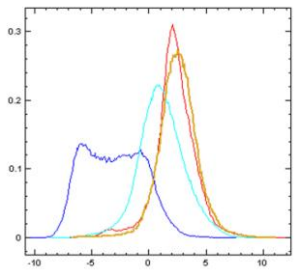

Figure 8: Typical canonical discriminant analysis of beef.
Transition from red to cyan (during MAP storage), transition from brown to blue (during aerobic storage).

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Further applications include the quantification of fat in raw meat, and the prediction of how well a piece of pork or turkey is cooked by combining RMSI with canonical discriminant analysis to monitor the frying treatment of minced and squared chunks of meat to predict adequate or over- and under-processing.

Contamination in Animal Feed

RMSI was shown to be an effective tool to detect the presence of contaminant in pig feed. In a similar way to the methodology used above samples of pig feed and contaminants were imaged, it was then a simple matter to combine the differences between the samples at each wavelength into a single image. Both poorly mixed and well mixed samples were easy to detect. A percentage level of contamination based on surface area was predicted automatically.

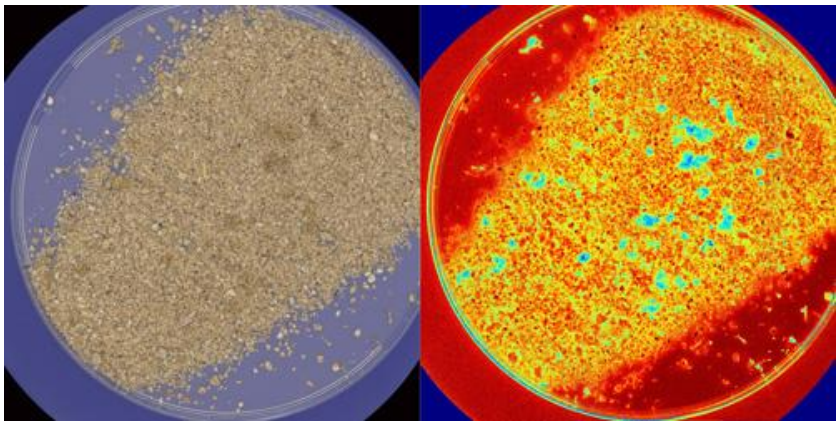

Figure 9. RGB image and pseudo image of contaminated animal feed

It is important to note that it is not a requirement to have a sample of the contaminant itself, RMSI can be used to detect contamination by unknown materials, and is used successfully to identify counterfeit pharmaceuticals.

Out of Specification or Contaminated Pharmaceutical Products

Multispectral imaging offers a rapid solution to screening for out of specification tablets and contaminated pharmaceutical powders. Since the response of the test material is measured simultaneously at up to 20 different wavelengths, very subtle changes in composition can be detected and automatically flagged.

The technique is perfectly suited for the objective measurement of tablet 'Elegance', a standard pharmaceutical test in which minor, major and critical defects are determined on a sub-sample; leading to acceptance or rejection of an entire batch. Tablet features inspected using multispectral imaging, both in the laboratory and on-line include:

1. Shape integrity (no missing parts)
2. Tablet colour
3. Foreign material (impurities, spots)
4. Cracks
5. Dispenser colour and defects

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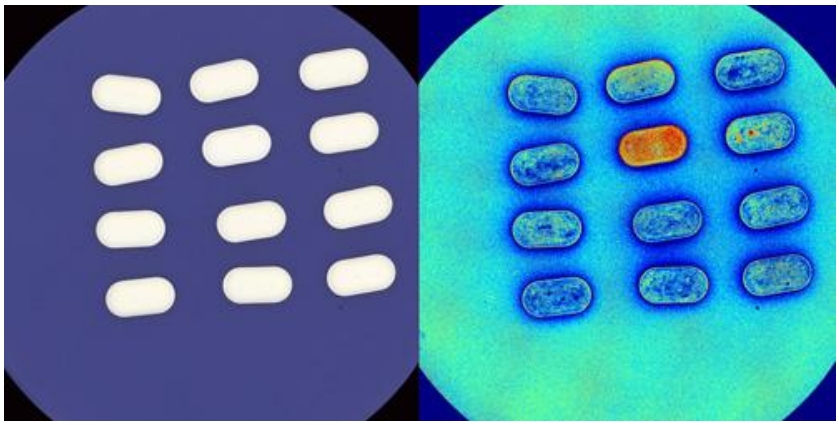

Figure 10: RGB and pseudo images showing the identification of increased active ingredient within the formulation of a single tablet.

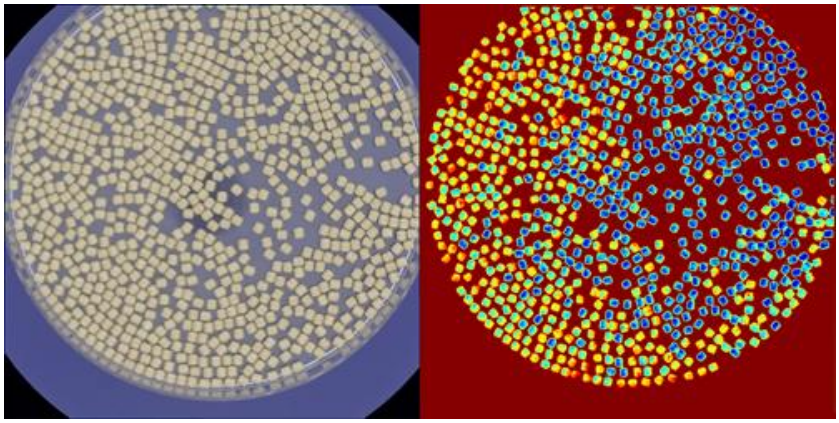

Figure 11: RGB and pseudo images showing automatic discrimination between coated and uncoated mini-tabs that are visually identical. This allows the operator to accurately quantify the level and homogeneity of tablet coating.

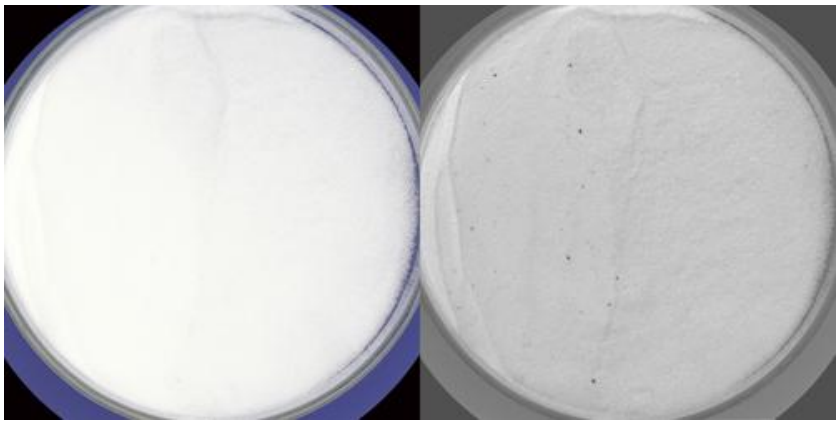

Figure 12: RGB and MNF (Maximum Noise Function) transformed images of pharmaceutical powder highlighting dirt and dust contamination. MNF is the imaging equivalent of Principle Component Analysis (PCA).

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Pharmaceutical Mixture Analysis

Understanding how well the ingredients of pharmaceutical formulations are blended is critical across various stages of the production process. RMSI can be used to recognise different powders in single layer and bulk presentation. As a result the success or otherwise of bulk mixing of two powders can be quantified.

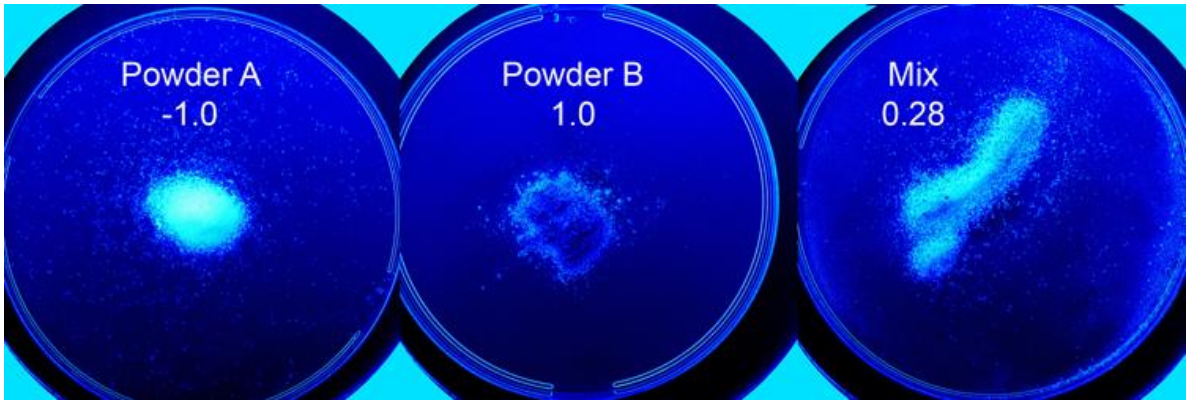

Figure 13: Each component within the mixing process is assigned a weighting based on its spectral profile. The 'Mix' value indicates to the operator the make-up of the sample from 'Powder A' and 'Powder B'.

Conclusion

Meeting government legislation and consumer demands in the regulated industries is costly. The security of materials in the food chain is of the utmost importance, and the presence of out of specification pharmaceutical products is a matter of extreme concern. Rapid Multispectral Imaging as an objective measurement of visual quality has now been developed into a technique accessible across these industries from the single lab to the multinational - meeting these concerns in a cost-effective manner.

This article has highlighted a very limited number of applications in quality control in the food, feed and pharmaceutical industries. After the initial development work all of the applications above can be carried out by non-specialised operators and none require difficult or tedious sample preparation. There are a great many further applications.

To learn more about VideometerLab 2 please visit www.analytik.co.uk (UK and Ireland) or alternatively visit www.videometer.com.

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