It used to be done by hand. A conveyor belt carrying potatoes, tomatoes, eggs, or whatever needed to be sorted, would be run past an army of sorters whose task it was to pick out, with lightning speed, any items that had gone off or were otherwise unsuitable for consumption.

Experiments with electronic sorting systems started quite a few years back, and it was twenty years ago that the first sorting machines using cameras actually appeared on the market. All these sorting systems do is to look at the colour on the outside of the fruit (or any other produce being scanned). Although in some ways the colour can tell us something about the fruit, it cannot tell us what it tastes like.

A notorious affair, and one that the Dutch market garden industry would rather not be reminded of, is that of the water-bomb tomato. For many years, Germany had been a major consumer of Dutch tomatoes, which looked perfect on the outside, but in fact were little more than water held together by a red skin. At least, that is what the Germans thought, and they switched to the much better-tasting Mediterranean tomatoes.

The best thing would be for an electronic sorter to give an indication not only of a tomato’s ripeness, but also of its taste. One good method of gaining such information without cutting up the fruit uses spectroscopy. A spectroscope is a device that enables the user to analyse the light, both visible and invisible, reflected by an object (a tomato, for example). The light consists of various

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**Spectroscopic views show**

flavour compounds of fruit and vegetables

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**The taste looks good**

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Until now, the only criteria for sorting fruit and vegetables were external properties such as blemishes and ripeness (insofar as they were visible).

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**BY ARNO SCHRUAUWERS**

For over two decades, fruit and other agricultural products have been sorted using the ‘electronic eye’. The eye selects purely by such external properties as colour, and cannot judge taste. Dr Gerrit Polder, an electrical engineer at Wageningen University, carried out his doctorate research at Delft University of Technology laying the foundations for an image processing system that can be used to determine the taste and smell of fruit as it is being sorted. Polder’s ‘taste viewer’ could also come in very useful in the pharmaceutical industry or in waste processing.
wavelengths that reveal something about the composition of the object. This is because every chemical has its own spectroscopic fingerprint. Applying the method to fruit or vegetables in essence allows their composition to be determined, not only at the surface, but also deeper below the skin. The spectroscopic method Polder used for his research can look a few millimetres inside a tomato and can even see straight through kernels of grain, allowing them to be checked for contamination by the fusarium fungus.

The object of the exercise is not to scrutinise every aspect of the fruit, since this would yield such a mass of data that processing it would slow down the sorting machine to the point where it would cease to be practical. A number of commercially available systems use various sensors sensitive to certain wavelengths, enabling them to determine the presence of essential nutrients inside the fruit. This can be done for any number of precise wavelengths, depending on the information required about the fruit. Rather than ‘nutrients’, Polder refers to ‘compounds’, a wider and more accurate term.

Image processing If you’re looking for information about the precise location of things within an object, its spatial layout, the traditional sensor technology mentioned above will be of little use. This is where image processing comes in. Using tomato ‘shots’, Polder has been trying to gather information about the fruit’s compounds by means of spectral image processing. To get the required information about the distribution of the compounds, he had to collect his data pixel by pixel.

Various techniques exist to record spectral images of fruit. One is to shine light of a certain wavelength onto a tomato, take a two-dimensional picture of the reflected light, then change the wavelength, take another picture, etc. The tomato has to remain in exactly the same spot, or the experiment will fail. Polder has opted for a method in which the entire reflection spectrum (or transmission spectrum if the light were to pass through the tomato) is recorded line by line by a special camera. The lines are chopped into pixels, each of which produces a complete spectrum. This means that information is gathered pixel by pixel. To ‘shoot’ the whole tomato, it has to be moved in small steps. This is hardly a viable method, since shooting a single tomato takes the better part of thirty seconds. In a real sorting machine the job has to be done in a fraction of a second.

Carotene To return to the tomato, which according to Polder is not just a nice fruit, it is also one of the most important horticultural products. What’s more, the boffins at Wageningen University know a thing or two about tomatoes. Unripe tomatoes are green, the colour of the chlorophyll that also makes the leaves on trees green. As tomatoes ripen, they produce lycopene, a vitamin-like substance that belongs to the carotene family. The fingerprint spectra of lycopene and chlorophyll are known. If you look at images taken at the right wavelengths, you can see that the concentrations of chlorophyll and lycopene inside the tomato change over time. The chlorophyll content decreases, while the lycopene content increases, turning the tomato red. Of course, it could be argued that the same can be observed using a straightforward RGB (Red/Green/Blue) colour camera, but in the course of his research Polder has discovered that colour cameras are not very good at determining ripeness. “I took pictures of a tomato on five consecutive days. It turned out that the RGB camera was unable to detect the difference in ripeness, whereas it was perfectly visible using the spectroscopic method.”

Flavours The spectroscopic method can also be used to determine the fruit’s content of a certain type of flavour (as the reader probably surmised on the basis of the above). Put simply, the height of a spectral peak at a wavelength specific to the substance under scrutiny is a measure of its content. However, it takes a lot of applied mathematics to unravel the spectrum before the concentrations of the constituents can be determined – but the fact remains that it can be done. Using a chemical analysis device called an HPLC (High Pressure Liquid Chromatograph) to determine the flavour concentration inside the tomato, a relationship can be established between the spectral readings and the
concentration of the flavour inside the fruit. Once this relationship has been established, there is no longer any need to drag every tomato through the chromatograph. Having obtained a pixel-based set of spectra, the concentration of the various constituents can be measured for each pixel. This helps to detect uneven ripening fruit or the first inkling of a blemish.

Polder: “This type of sorting system is much more flexible in its applications than other sorting systems that use fixed filters and sensors. You can measure any substance you like without having to modify the sorting system. The enormous amount of data the system produces does remain a slight problem, although the number of data can easily be reduced by using only the parts of the spectrum that tell us something about the substance we’re looking for. One could also use the full resolution of the sensor, which would yield the best possible readings, but this would produce hundreds of megabytes per image and still would not produce any additional information, the optical system being the limiting factor. This method is eminently suitable for measuring a large number of constituents. Of course, and I have become well aware of this, it is essential to ensure that the system is accurately calibrated.”

Test  Polder was able to demonstrate his skill measuring the presence of fusarium in grain using a transmission light method. The grain was placed between a halogen light source and the camera, a technique known as transmission spectroscopy.

Polder: “These measurements are important for organic farmers who are not allowed to use pesticides.”

Other industries also use spectroscopic systems, according to Polder, who gained his B.Sc. in electrical engineering in Arnhem.

“I know that some of my colleagues are working on systems for separating waste flows using the spectroscopic method, and a colleague in Austria is working on a way to extract various types of plastic from waste material, something for which the method is eminently suitable.”

If the model is applied to all the pixels of the tomato, it produces concentration images of the various compounds. This figure shows the concentration images of five different compounds of three different tomatoes. Dark pixels indicate low concentrations, lighter pixels indicate higher concentrations. These images can show local differences in concentration that may be caused by non-uniform ripening.

Creating a regression model as shown in the previous images requires a costly reference method, e.g. HPLC. For this figure, no reference method was used. Instead the analysis was carried out using Independent Component Analysis, a new statistical technique. In this case two components are found which more or less match chlorophyll and lycopene. This figure shows how the concentrations of these components decrease and increase as the tomato ripens.
Testing having been successful, the time has come to market the method. After all, Polder’s doctorate research formed part of the Innovative Research Programme for image processing funded by the Ministry of Economic Affairs. A requirement of the programme is that the industry participates in the research project. Did they?

Polder: “Yes, they did, in the form of Greefa bv, one of the world’s major manufacturers of sorting equipment for fruit and vegetables. I just hope the industry takes it from here.”

Of course, although Polder has demonstrated that the spectroscopic method is perfectly suitable for determining the content of flavours and aromas and for classifying fruit and other produce, the system is still a bit on the slow side. Polder: “The problem is that large quantities of data must be manipulated in a short space of time. The test system still uses 80 megabyte images that have to be processed in some way. A practical system would have to be able to process several images every second. This could be done by using filters specific to a certain substance as well as other types of cameras, such as cmos cameras, which can address specific pixels, and so reduce processing times.”

Anyway, that’s all practical stuff. At least the foundations have been laid.

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