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Rapid Quality Assessment of Fruits with Machine Vision System

Machine vision systems are integrated into many sorting lines designed to grade fruits and vegetables. Additionally, in newly installed sorting lines spectroscopic analysis methods in the visible range and with NIR spectroscopy are being used for grading produce on fruit dry matter and refractrometric soluble solids content. As a source of light, low-cost silicon based detectors and halogen lamps are used, which cover a wavelength spectrum up to 1100 nm. Monochromatic laser diodes could provide a new method of sorting according to fruit flesh firmness in the future. This was tested on kiwi fruits. In the laboratory setup the three classes "soft", "premium" and "hard" were distinguished with a 16.3% misclassification error. The data processing takes less than 70 ms per image on a personal computer (AMD64, 2.19GHz) which makes the technique suitable for commercial online assessment.

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Keywords

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Quality assessment and grading is essential before selling agricultural produces to the customers. The current sorting line manufacturers provide automatic and robust systems to satisfy various needs from cherries to melons. Capacity is the key feature of such systems. Typical machines perform 5 to 10 analyses per second per lane. Calculating with the fruit size of 120 mm, the estimated velocity of the produces is between 2 and 5 km/h (eq.1). The fastest sorting lines apply a velocity between walking and riding a bicycle.

$$v_{\min} = 5\frac{piece}{s}\times 120\frac{mm}{piece} = 2.16\frac{km}{h} \qquad (1)$$

The velocity of the lanes is adjusted to increase capacity without increasing the probability of mechanical injuries.

The heart of the grading system is the camera. It is therefore required to work with at least 10 to12 fps (frames per second). Typical low cost cameras operate with 25 to 30 fps. The top class high speed cameras are able to reach 5000 fps. The similar velocity calculation with this 5000 fps results in a supersonic sorting line. The 5000 fps is exaggerated, but 10 fps is insufficient. The camera speed above 10 fps is utilized to repeat the measurement on each fruit. This repetition is very useful if fruits can roll in front of the camera due to the transportation on rolling wheels or conveyor belts of slightly different velocity. Analysis of rolling fruits means that almost the whole surface is scanned.

The grading procedure firmly depends on the type of the camera. Gray scale (so called BW = black and white) camera modules are used to measure size and compare shape to templates of gold standards. Colour (so called RGB = red, green and blue) camera modules are used to measure the average colour of the surface, colour pattern, and detect defects like mould [1]. The average colour and the coverage with blush colour on the surface are the most commonly used attributes, because consumers' decision is done mainly in consideration of these traits.

Optical filters are commonly mounted onto the objectives of these cameras. The filters enhance interesting parts of the spectra. The procedures utilizing NIR or UV ranges of the light may detect mechanical defects early, before they are visible on the surface. The range of NIR is also used when fruit compounds and internal quality are in the focus [2]. The most important quality parameter for many compact fruits is presently the fruit flesh firmness defined as the maximum force at the first spontaneous tissue break, which cannot precisely measured with existing non-destructive methods.

Backscattering imaging

The technique of backscattering imaging differs from the traditional approaches in machine vision. This measurement takes place in a dark chamber where a single light beam is used to illuminate a point on the surface of the fruit (*Fig.1*). The light penetrates into the tissue, and photons are absorbed or migrate in different directions (scattered). Absorption is related to the fruit compounds, such as sugar, water, pigments, etc. Scattering depends on the cell size, inter- and extracellular properties of the tissue. The wavelength of the light also affects the results. Backscattering imaging with monochromatic light in the range of 670 nm to 1060 nm has been used to predict soluble solids content by means of absorption changes and firmness by using the scattering information of fruits [3]. The advantages of the narrow wavelength bands and low dispersion angle lead to the application of laser modules.

Experiments with kiwifruits

In the present study, we selected the laser sources emitting at 670 nm (Global Laser Ltd., UK) and 785 nm (Newport Corp., USA), related to the chlorophyll absorption and scattering, respectively. The energy of the laser diodes was below 50 mW which did not damage the fruits during acquisition. The geometry was adjusted to 0/15°. This low incident angle was beneficial because the viewpoint of the camera was close to the laser beam. The standard CIE 0/45° geometry is frequently used in image processing, but in this case, increasing the incident angle

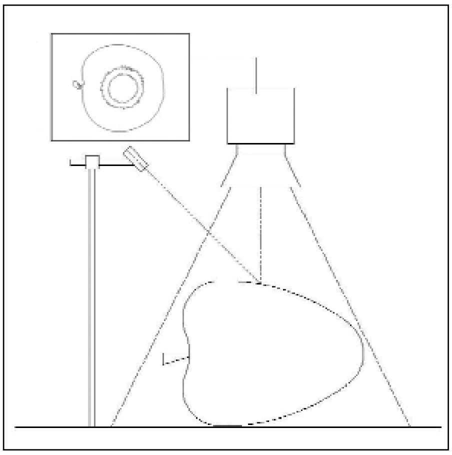

Fig. 1: Typical setup for backscattering imaging

may prevent photons from entering into the fruit. Colour camera of 3CCD (JVC Ltd., Japan) was mounted due to the visible laser lights. Pictures of 768x572 pixel size with 0.03 mm/pixel resolution were captured.

Kiwifruits (*Actinidia deliciosa 'Hayward'*) were tested in the experiments. The sample set consisted of commercial grades of „soft“, „premium“, and „hard“ pieces. This classification was performed by an expert sensory panel with daily experience on manual sorting. The goal of the analysis was to classify fruits into grades.

The colour image was transformed into gray-scaled values of Luminosity (eq.2) and this layer was used in further analysis.

$$L = 0{,}30\ R + 0{,}59\ G + 0{,}11\ B \qquad (2)$$

Dynamic k-cluster method was applied to segment the backscattering area and select ROI (region of interest). The coordinates of the incident point were calculated as weighted average with the weights of Luminosity. The Luminosity value of each pixel was collected relative to the incident point (*Fig. 2*). Three profiles were created as distance versus average and maximum Luminosity values and the variances. Three key positions were selected on the curves according to the distance of the inflection point and tangent lines forward and backward from this position. Computation was based on the first derivatives instead of time consuming non-linear curve fitting. Twenty-one parameters were finally extracted such as values at the three key locations and their comparisons within and between profiles.

The calculation of these parameters took less than 70 ms for one picture on a personal computer (AMD64 Athlon X2, 2.19 GHz) without special code optimization. This speed enables 14 analyses per second, theoretically.

Results and discussion

The firmness of each kiwifruit was also measured with a universal testing machine (Zwick Materialpruefung Co. Ltd., Germany) using Ø4 mm cylindrical probe with 15 mm maximal penetration depth and 200 mm/min velocity. New limiting values were defined around grade "premium", which had the best quality for consumption. Bayesian optimization technique was applied to calculate thresholds. The variance and the range of this optimized grade decreased compared to the sensory panel (*Table 1*). The Bayesian thresholds were tested on independent samples and finally an optimum range might be recommended for more objective grading based on the firmness.

Partial Least Squares (PLS) regression was performed on the basis of the Luminosity profiles to estimate the maximal force of deformation. This non-destructively estimated firmness was also included in the classification and statistical analysis, increasing the number of parameters up to 22.

Classification of grades

The laser diode of 785 nm was selected for classification of commercial grades. The backscattered amount of light of this wavelength is not likely to be affected by the pigments of fruits. The second advantage of this decision is that this wavelength is inside the operating range of the low cost CCD sensor arrays.

The linear discriminant analysis method was used to classify pieces. The leave-one-out cross validation technique was applied due to the small number of fruits (n = 98), especially in the grade "soft". The optical parameters of the backscattering gradient obtained 73.47% accuracy. This accuracy was increased up to 83.68% with estimated force values by the PLS (table 2).

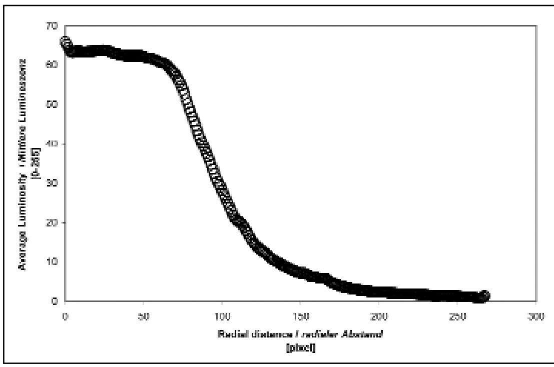

Fig. 2: Average luminosity profile for a kiwifruit

Sample	**Minimum**	**Mean**	**Maximum**	**Variance**
Original (sensory)	1.492	2.757	7.174	2.079
Optimized (Bayesian)	1.565	2.248	3.122	0.1708

Table 1: Maximum force [N/cm^2] of kiwifruits for grade „premium“

Estimated	**Commercial grades**		
	Soft	**Premium**	**Hard**
Soft	9	2	0
Premium	2	28	7
Hard	2	3	45
Total	13	33	52

Table 2: Classification results with the non-destructive image processing and standard method based on commercial grades

Conclusions

The analysis of backscattered light and visible-NIR spectroscopy were reported to be able to measure soluble solids content and firmness of apple fruits. In the present study, the three commercial grades of kiwifruit differed in ripeness, which was primarily detected by firmness. The evaluation of laser induced backscattering at the wavelength of 785 nm resulted in 83.68% correctness of classification.

Further improvements of this procedure may result in a method that offers an additional or alternative technique for sorting lines. The small scale laboratory experiments already reached an acceptable speed with less than 70 ms per picture.

Literature

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