Modelling of Apple Fruit Growth by Application of Image Analysis

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SUMMARY

The possibility of RGB image processing and analysis for modelling of the development and growth of apple fruits was investigated during the two seasons under the orchards experiment in the four-years old 'Golden Delicious' and 'Gala' variety. The fruit detection depended significantly on the size and fruit's colour of each growing stage, thus the correlation coefficients were continuously increasing from r=0.71 (2001) and r=0.73 (2002) after fruit tinning in June, up to r=0.88 (2001) and r=0.89 (2002) at harvesting in September respectively. The yield at harvest was estimated with the accuracy of 94% and 101% for 'Golden Delicious' and with 106% and 92% for 'Gala' respectively, whenever based on images captured on June 22 2001 and June 26 2002. Therefore, the image algorithm was proved to be equal or even better method for estimating the yield at harvest than the common 'Prognosefruit' method (accuracy 101% and 77% for 'Golden Delicious' and 72% and 63% for 'Gala' respectively)

KEY WORDS

RGB image, apple, yield, forecast

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INTRODUCTION

Modelling of apple fruit development and growth represents one of the most interesting topics for the scientists for the long period. However, in the recent decades biological simulation models have grown in popularity as a substitute for a large-scale orchard experiments due to increased computer capacity (Oriade and Dillon, 1997). Despite of all methods developed by the horticulturists, the mechanistic 'Prognosfruit' (Winter, 1986) remains the most accepted method by the European apple and pear producers (Lambrechts, 2001, Ramos and Lieberz, 2003). However, the time consuming measurements of required parameters avoid to apply the method on a single orchard level, therefore a new approach for effective data acquisition and image analysis algorithms has been developing and investigating in order to determine the number and diameter of fruits for estimation the yield at harvesting (Stajnko et al., 2004)

In the last decades the implementation of computer vision has been widely adopted for building the fruit detection algorithm applied in the fruit grading procedure on the packaging lines. Several industrial algorithms for processing the main steps of the image analysis algorithm under the artificial lighting in chambers automatically were represented by many authors (Jimenez et al. 1999).

However, whenever operating in the open field with sunlight as an illumination source the image quality decreased significantly, thus the controlled illumination was suggested and applied in most cases. Already with the first apple-picking robot 'MAGALI', the detection of different varieties of apple fruits was possible only under a dark background assured by a protective coverage (Grand D'Esnon et al., 1987). Furthermore, Peterson et al. (1999) installed a special fibre-reinforced drapery on the apple-harvesting robot to block the influence of natural light conditions. Also the citrus robot for harvesting oranges (Juste and Sevilla, 1991) and strawberry harvesting robots (Kondo et. al., 1998) needed an artificial light sources although the ripen fruits were red colour.

The accuracy of apple fruit detection algorithms was crucial parameter whenever evaluating the efficiency of the robot harvesting. However, the reported precision varied greatly from 41% (Kassay, 1992) to 85% (Kataoka et al., 1999) and 95% (Petersen et al., 1999) depending significantly on the fruit colour, the applied filters and thresholding techniques.

In our research the number of fruits was determined also prior the harvesting period, when the colours of the fruits did not differ substantially from the colour of leaves. Thus the main objective of this paper is to demonstrate and evaluate the applicability of the method for predicting the number and the diameter of the apple fruits needed for modelling the current and harvested yield in the apple orchard.

MATERIALS AND METHODS

During the vegetation period June-September 2001 and 2002, ten apple trees (*Malus domestica* Borkh. of the 'Golden Delicious' and ten of the 'Gala' variety were examined in the Faculty's orchards (lat. 46°32' N, long. 15°33'5 E). Four year-old apple trees were trained as a super spindle and planted at a spacing of 2,8 x 0,7 m. All trees were grafted on the M9 rootstock and the rows were oriented from East-North to West-South. In both years five developing stages of apple fruits were selected for capturing images during the fruit's growth and ripening (Table 1).

For capturing images a CCD OLYMPUS 3030 camera with the Flash setting program was used with three different resolutions 2048x1536, 1600x1200 and 1280x960 pixels from a distance of 1,8m and the angle of 90° towards the tree row.

Table 1. Capturing plan

Stage	Date	
	2001	2002
After a fruit tinning	May 23rd	May 26th
One month later	June 22nd	June 26th
One month later	July 11th	July 9th
One month later	August 18th	August 8th
Harvesting 'Gala'	August 20th	August 13th
Harvesting 'Golden Delicious'	September 21st	September 2nd

Fruit detection algorithm

The applied five-step apple fruit algorithm based on a colour and a shape detection. However, the fruits of the chosen apple varieties changed their colour according to the growing stage significantly, thus a robust and adjustable algorithm was developed.

As seen from the Figure 1, all the fruits could not be detected on the original RGB images at once, thus a sample image from each series was first trained by dividing it into three basis planes (R image, G image and B image). Whenever any of those images did not fulfill the required contrast between the objects, additional transformation to the images of I (illumination), H (hue) or S (saturation) proceeded. After that on the basis of the histogram analysis, the most fitting image was selected for each fruit developing stage separately. For that reason, in the 'Golden Delicious' variety the R image was chosen for further processing in the first stage (May 23rd 2001 and May 26th 2002) and the G image for all other stages (Figure 2). Contrary, in the 'Gala' the G image was selected in the first stage and the R image for all later stages.

In the second stage the selected image was first filtered by applying of a specified size of kernels (3x3 pixels) to remove the noise and the 'connectivity-4' function, which divided the border pixels belonging to one or another object. Then, by applying of precise threshold values the binary image was created for

Figure 1.
Original RGB image showing the 'Golden Delicious' (a) and 'Gala' tree (b)

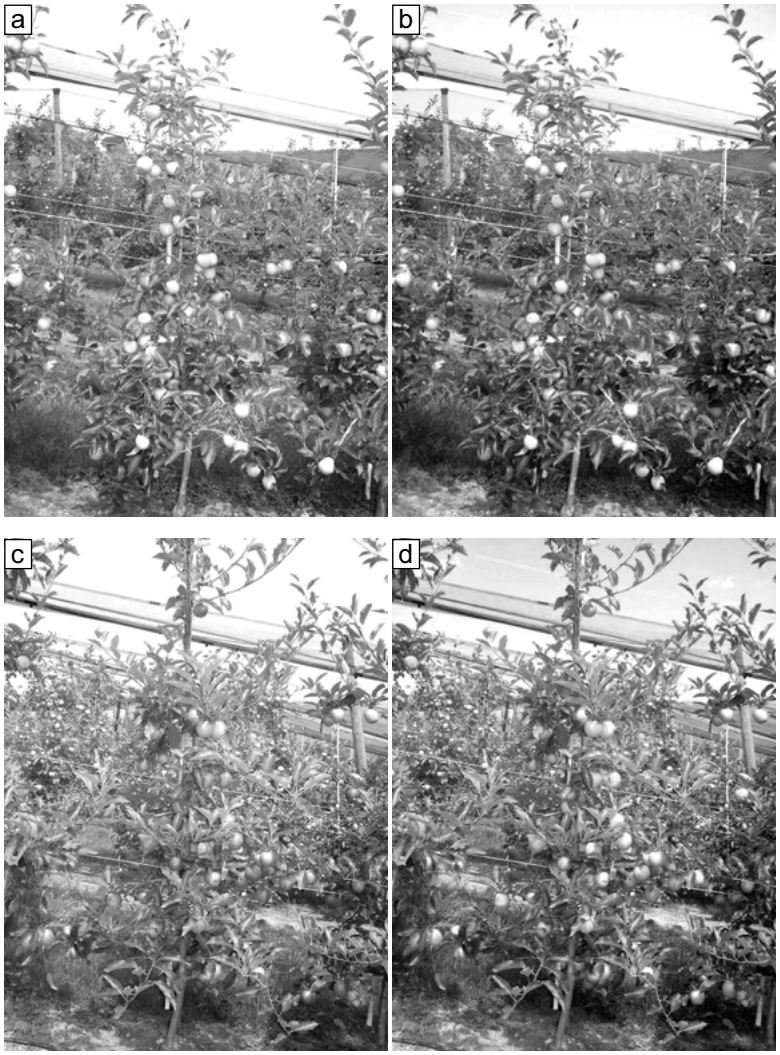

Figure 2. Transformed G (a) and R (b) image of the 'Golden Delicious' and G (c) and R (d) image of the 'Gala'

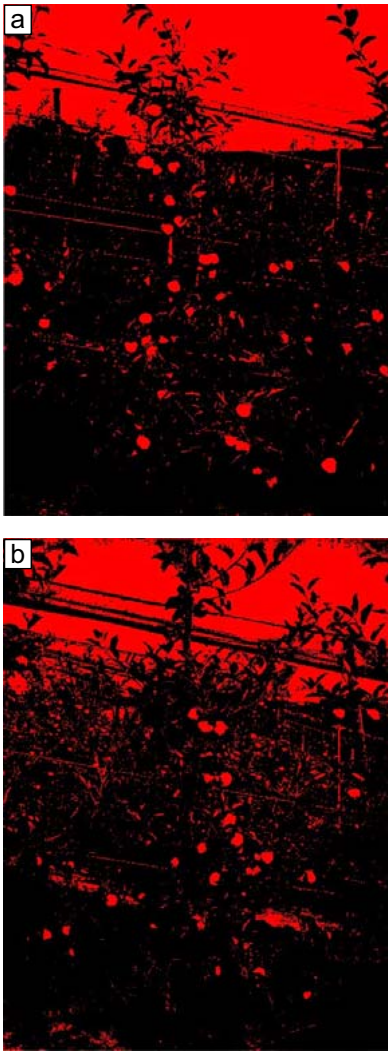

Figure 3. Binary image processed from the 'Golden Delicious' (a) and the 'Gala' image (b)

each developing stage (Figure 3). After that, in the third stage, a two-step object detection proceeded automatically by using of the ellipse template in the first step and the whole apple fruit template in the second step. Finally, the remaining objects (Figure 4) were counted and the standard morphological

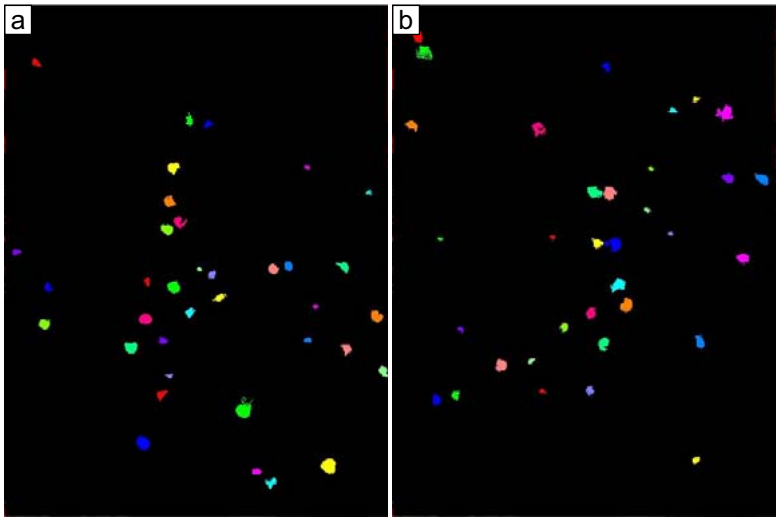

Figure 4.
Detected fruits of the 'Golden Delicious' (a) and the 'Gala' image (b)

characteristics (longest segment, major axis, minor axis, area, perimeter, compactness and elongation) were analysed on each object separately. In the last stage the current yield was estimated on each image by applying of derived Mitchell's (1986) equation for both varieties as follows:

$$Y_{GoldenD} = \frac{N \cdot 0,504 \cdot D^{2,9602}}{10^6} \qquad (1)$$

$$Y_{Gala} = \frac{N \cdot 0,4059 \cdot D^{2,9602}}{10^6} \qquad (2)$$

where $Y_{GoldenD}$ and Y_{Gala} represents the yield per tree in kg, N the number of fruits per tree and D the average fruits diameter of a specified developing stage.

For performing the above-described algorithms our own code was developed in the IMAQ Vision 5.1 and Labview 6.0 Package Program.

RESULTS

The estimated number of apple fruits per tree by the image analysis as well as manually counted fruits is represented in the Table 2. As seen, the established correlation coefficient varied in the 'Golden Delicious' between 0.71 and 0.89 in 2001 and from 0.73 to 0.89 in 2002 respectively. Very close correlation was also established for the 'Gala' variety whereas in 2001 the coefficients varied from 0.73 in June to 0.89 at harvest and from 0.76 in June to 0.91 at harvest in 2002 respectively. A close correlation between detected and manually counted number of fruits at the harvesting were already reported from Kondo et al. (1998) whenever investigating the algorithms for the strawberry harvester and Kataoka et al. (1999) for the apple harvester. However, our fruit detection algorithm was proved to be a successful toll also for predicting the number of fruits prior harvesting, which was an important parameter for estimating the yield.

On the other hand, whenever evaluating the estimated average fruit's diameters per tree with manual measurements at different developing stages of apple fruits (Table 3), it may be seen, that it was practically equal to the manual measurements at all developing stages during the vegetation in both varieties. However, in the 'Golden Delicious' the correlation coefficient varied greatly from 0.19 to 0.55 in 2001 and from 0.36 to 0.79 in 2002 respectively while in the 'Gala' the coefficient rised from 0.77 to 0.88 (2001) and from 0.34 to 0.80 (2002). The first reason for lower correlation coefficients lies in the fruit detection algorithm, which is based on the

Table 2. Number of apple fruits estimated by image analysis and manually counted

Experiment	May		June		July		August		Harvest	
	M	IA	M	IA	M	IA	M	IA	M	IA
Golden Delicious 2001	535	362	486	446	497	454	392	391	392	396
r	0.709072*		0.767713*		0.783406*		0.857379		0.88091**	
Golden Delicious 2002	406	331	405	345	378	397	379	313	368	385
r	0.73084*		0.78744*		0.845814*		0.942209**		0.89057**	
Gala 2001	268	310	268	281	268	293	268	298	245	279
r	0.73084*		0.78744*		0.845814*		0.942209		0.89057**	
Gala 2002	397	407	397	378	376	365	376	340	336	316
r	0.761025*		0.791655*		0.760875*		0.886727		0.919246**	

M – manually; IA – image analysis; * $p<0.05$; ** $p<0.001$

Table 3. Average diameter (mm) of apple fruits estimated by image analysis and manually counted

Experiment	May		June		July		August		Harvest	
	M	IA	M	IA	M	IA	M	IA	M	IA
Golden Delicious 2001	28	28	38	38	63	63	68	67	75	74
r	0.19384		0.241295		0.070021		0.567918*		0.549651*	
Golden Delicious 2002	31	29	50	49	56	47	75	72	78	77
r	0.365421		0.489393		0.53044*		0.636635*		0.796106*	
Gala 2001	39	39	51	49	56	57	70	69	78,2	76
r	0.77192*		0.796557*		0.780655*		0.880034**		0.769869*	
Gala 2002	42	41	54	53	58	58	76	76	79	80
r	0.34849		0.33026		0.750391*		0.802161*		0.76747*	

M – manually; IA – image analysis; * $p<0.05$; **$p<0.001$

Table 4. Average yield per tree (kg) estimated by image analysis and manually counted

Experiment	May		June		July		August		Harvest	
	M	IA	M	IA	M	IA	M	IA	M	IA
Golden Delicious 2001	0.80	0.62	1.71	2.00	7.10	6,24	7,44	7,83	7,85	9,85
r_{stage}	0.55		0.76*		0.53		0.71*		0.70*	
$r_{harvest}$	0.55		0.58		0.43		0.46			
Golden Delicious 2002	0.41	0.40	1.76	1.92	1.62	2,03	5,34	5,32	5,07	8,13
r_{stage}	0.93*		0.94*		0.91*		0.97*		0.92*	
$r_{harvest}$	0.15		0.05		0.37		0.31			
Gala 2001	0.82	0.81	1.56	1.30	1.65	2,29	1,68	2,45	2,60	4,27
r_{stage}	0.86*		0.78*		0.10		0.12		0.58*	
$r_{harvest}$	0.25		0.16		0.08		0.08			
Gala 2002	0.97	0.99	2.17	1.93	2.53	2,47	5,56	4,95	7,64	5,49
r_{stage}	0.29		0.64*		0.84*		0.66*		0.69*	
$r_{harvest}$	0.06		0.68*		0.24		0.49			

r_{stage} – correlation in the particular stage; $r_{harvest}$ – correlation between the image analysis in the stage and the harvest
M – manually; IA – image analysis; * $p<0.05$; **$p<0.001$;

longest segment measurement. The second one is due to a very levelling diameter among all sampled trees caused by chemical tinning, so even the small deviation of the diameter resulted in the great fall of the correlation.

The current yield per tree was estimated by applying of equations 1 ('Golden Delicious') and 2 ('Gala'). The correlation coefficient between manual measurements and imaging estimation of the particular developing stage is represented in the Table 4. As seen, in the 'Golden Delicious' coefficients varied from 0.55 to 0.76 in 2001, while in 2002 remained very stable altering only from 0.91 to 0.97. The obvious difference between both years was due to the early frost damages and summer heats in 2001. For the 'Gala' the coefficients varied greatly in both years, although the negative effect of the weather conditions has larger influence in the first year.

Contrary, whenever modelling the development of the fruit yield on the basis of image analysis and comparing it with manual measurements, almost identical growing curves were established for the 'Golden Delicious' (Figure 5) and the 'Gala' (Figure 6) respectively. With the very close correlation for both varieties in all years, the image algorithm has show a good possibility for modelling of the yield at harvest already after the fruit tinning in June.

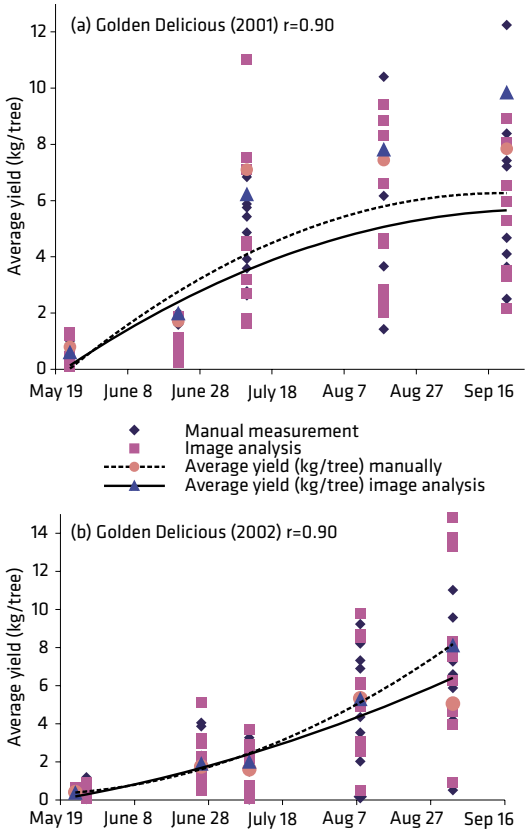

Figure 5: Growing curves of the 'Golden Delicious': (a) 2001 and (b) 2002 experiment

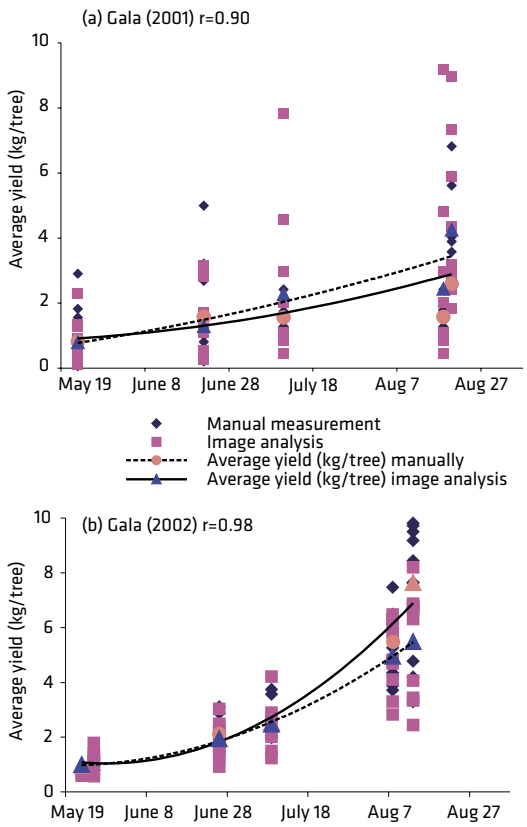

Figure 6. Growing curves of the 'Gala' (a) 2001 and (b) 2002 experiment

CONCLUSION

A new approach for modelling of apple fruit development and estimation of the harvested yield under orchard conditions was researched in our investigation. Based on captured RGB images, and grown through the several processing and analysis procedures, the presented algorithm shows a great possibility for modelling of yield development in the 'Golden Delicious' and 'Gala' variety during the vegetative period. However, future work should be focused on improving the algorithm, so it is able to detect also partially hidden spherical objects.

REFERENCES

Jimenez A.R., Jain A.K., Ceres R., Pons, J.L. (1999). Automatic fruit recognition: a survey and new results using Range/Attenuation images, Pattern Recognition 32, 1719-1736

Juste F., Sevilla F. (1991). Citrus: A European project to study the robotic harvesting of Oranges, in: Proc. 3rd Int.Symp. Fruit, Nut and Vegetable Harvesting Mechanization, Denmark, Sweden, Norway, 331-338

Kassay L. (1992). Hungarian robotic apple harvester, ASAE Paper No. 92-7042

Kataoka T., Bulanon D.M, Hiroma T., Ota Y. (1999). Performance of Robotic Hand for Apple Harvesting, ASAE Paper No.993003, 11 s. MI.:ASAE

Kondo N., Hisaeda K., Monta M. (1998). Development of Strawberry Harvesting Robotic Hand, ASAE Paper No.983117,ASAE St. Joseph, MI-USA, p .1- 7

Lambrechts G. (2001). Apple EU 2001 Forecast 2001, Prognosfruit 2001, p. 1-8 http://cmlag.fgov.be/dg2/fr/Communications/prognos-algemeen.pdf

Grand D'esnon, A., Rabatel G., Pellenc R. (1987). Magali: a self-propelled robot to pick apples, ASAE paper No. 87-1037, St.Joseph, MI 49085-9659

Mitchell P.D. (1986). Pear fruit growth and the use of diameter to estimate fruit volume and weight, Hort Science 21, 4, 1003-1005

Oriade C.A., Dillon C.R. (1997). Developments and biophysical and bio economic simulation of agricultural systems: a rewiev. Agricultural Economics 17, 45-48.

Peterson D.L., Anger W.C., Bennedsen B.S.,Wolford S.D. (1999). A system approach to robotic bulk harvesting of apples. ASAE Paper No. 99-1075

Ramos K., Lieberz S.M. (2003). Prognosfruit 2003 – European Crop Forecast Convention, 7 s., http://www.fas.usda.gov/gainfiles/200308/145985760.doc

Stajnko D, Lakota M, Hočevar M. (2004) Estimation of number and diameter of apple fruits in an orchard during the growing season by thermal imaging. Comput. electron. Agric. 42, 31-42.

Welte H.F. (1990). Forecasting harvest fruit size during the growing season. Acta Horticulturae 276, 275-282

Winter F. (1986). Modelling the biological and economic development of an apple orchard. Acta Horticulturae, 160, 353-360.

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