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# Application of image analysis for monitoring growth and development of apple fruits *'Malus domestica'* Borkh. during the growing season

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A new approach for counting apple fruits, measuring fruit's diameter and estimating the current yield under flash lighting conditions in the fruit tree plantation was developed and tested in the 2002 and 2003. During the vegetation images of ten trees were captured five times in both years by applying CCD camera. A close correlation was established between manually counted number of fruits per tree and the estimated number of fruits (r=0.70 to 0.88). However, relatively lower coefficient was estimated for measuring the fruit's diameter (r=0.33 to 0.88). The established correlation coefficients for the average yield per tree was also increasing with the ripening of fruit significantly (r=0.28 to 0.87), therefore the developed algorithm promises a good possibility for forecasting the yield at harvesting on the basis of June and July samples.

Keywords: image analysis, apple, *Malus domestica*, yield, fruit, diameter

## INTRODUCTION

Forecasting the number of fruit and size at harvesting represents together with ecological, varietal and plantation parameters the basis for prediction of future yield and planning of incomes (Welte 1990). In the late decades a considerable research has been conducted in order to develop a viable method for the apple yield prediction, however, today the 'Prognosfruit' Forecast model, developed and introduced in practice by Bavendorf Research Station (Winter 1986), is the only method for yield quantity and quality estimation accepted by the European apple and pear producers. The model is based on the yield capacity of the observed growing unit (trees, variety, rootstock, orchard age and inclination, area), the fruit-set density of the growing unit in the given year and the average fruit mass at a harvesting date (Winter 1986). The accuracy of the method prediction lies between 97 to 98% of future yield for large growing areas with similar environmental conditions (žTrento' in Italy or 'Lake Constance' in Germany) or for estimating average yield for whole countries (Lambrechts 2001). However, as seen from the Prognosfruit annual report 2001, 2002 differences between the forecast and harvested yield have varied from –21.9% to +14.1% per hectare in 2000, depending on the apple variety and country growing region (Lambrechts 2001; Ramos and Lieberz 2003).

Despite of the proven efficiency, the main disadvantage of the method represents the time-consuming counting measurements of required parameters, which do not allow to predict the future yield in every individual plantation.

Possible enhancement of such forecasting methods can be achieved by applying visual techniques in collecting of samples. Nowadays, in fruit growing, vision algorithms are often used for detecting fruits by harvesting machines in experimental cases, but only under controlled lighting conditions (Jimenez et al. 1999). In the last two decades, numerous researches have been involved in the application of image analysis for detecting fruits and guiding the robot hands of autonomous harvesters.

As reported by Grand D'Esnon et al. (1987) it was possible to detect different varieties of apple fruits when a protective coverage got a dark background with the first version of apple harvesting robot 'MAGALI'. Also Juste and Sevilla (1991) created the citrus robot for harvesting oranges, which required two flashlights for proper fruit detection. When testing three different strawberry harvesting robots Kondo et al. (1998) mentioned that there was also a constant need for artificial light sources although the ripen fruits had red colour.

Similar artificial lighting requirements were suggested by Tian et al. (1997), when sensing of different plants, and discrimination of weeds from crop plants and soil was studied by using visual system under controlled illumination.

As noticed by Steward and Tian (1998) a direct sunlight caused substantial intensity differences within the images due to shadows and reflection from shiny leaf surfaces, thus Peterson et al. (1999) installed a fibre-reinforced drapery on the apple harvesting robot to block the influence of natural light conditions and increased the accuracy in detection of red coloured 'Empire' variety up to 95%.

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For determining the colour and shapes of weeds in the cereal fields Perez et al. (2000) used a variant of well-known Red/Green ratio measurement for predicting the number of seedlings and estimating the relative leaf surface of crops and weeds more accurately.

With additional development of the shape detection algorithm Stajnko and Lakota (2001) reported the establishment of a close correlation between the number of fruits estimated on the images captured on the sunny side of apple trees and manually counted fruits, while detecting yellow and green-yellow 'Golden Delicious' fruit at the harvesting. However, to create a homogenous illumination across the whole image the application of the artificial light source (flash) was required on the sunny as well as shadow side of the tree row.

In our research, the number of fruits was also determined prior the harvesting period, when the colours of the fruits did not differ substantially from the colour of leaves. To overcome the problem of insufficient colour gradient caused by lighting characteristics, the image arithmetic of

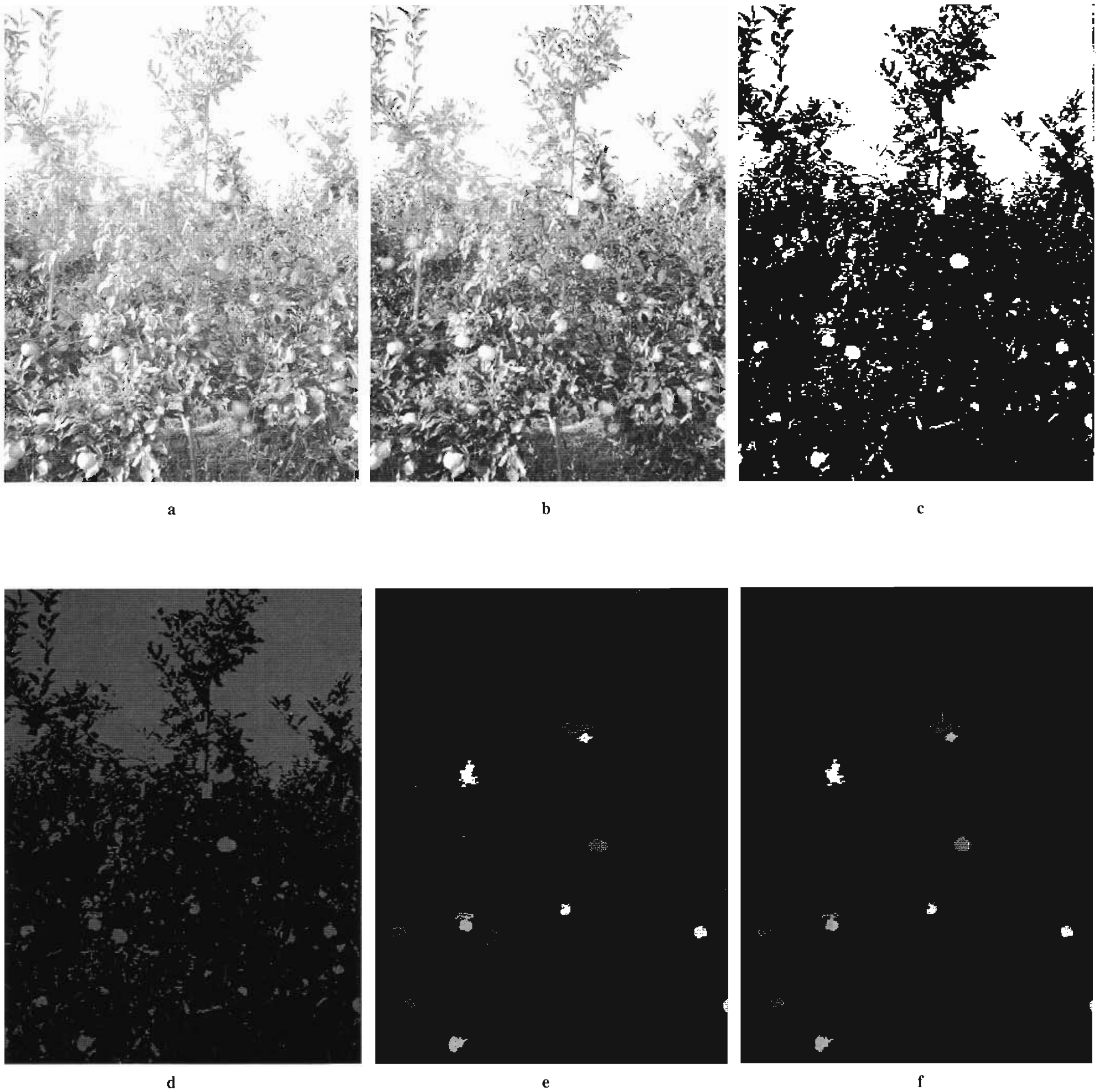


**Fig. 1. A sample image of 'Gala' apple tree captured on August 8th 2003; (a) original RGB image, (b) R image, (c) after filtering, (d) binary image, (e) objects after first template, (f) final results**

the basic colour planes followed by a two-template application and objects classifier evaluation was used. 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 calculating the current and future yield in the fruit tree plantation.

## MATERIAL AND METHODS

During the vegetative period May-August 2002 and 2003, ten apple trees (*Malus domestica* Borkh.) were examined in the Faculty's apple orchard (lat. 46o32' N, long. 15o33'5 E). Apple trees were planted in 1999 using the variety 'Gala' grafted on the M9 rootstock. The experiments were performed each time around noon, to ensure equal effect of the sunlight. The following developing stages of apple fruits were selected for capturing images in the crucial stages of the fruit's growth and development:

| | | |
|---|---|---|
| 1. stage - after fruit drop | June 6 2002 | May 26 2003 |
| 2. stage - one month later | June 22 2002 | June 26 2003 |
| 3. stage - one month later | July 11 2002 | July 9 2003 |
| 4. stage - beginning of ripening | August 14 2002 | August 8 2003 |
| 5. stage - collecting fruit | August 20 2002 | August 28 2003 |

Each time one series of pictures were captured on the sunny side of trees and another series on the shadow side, both from the distance of 2.0 m at an angle of 90° degrees to the planting row. Concurrently, on each photographed tree all fruits were manually counted and the diameter of ten sample fruits was measured by applying a sliding calliper. Results were later compared with the image analysis calculations.

A CCD OLYMPUS 3030 camera with the Flash setting automatic program was used for capturing images with the resolution of 1280x960 pixels, since the best possible image quality 2048x1536 was found in our earlier experiments to reduce the processing speed significantly. The analysis of the images was carried out with a personal computer (PC) with a 350 MHz processor and 256 MB random access memory (RAM).

### Fruit detection algorithm

The apple fruit recognition algorithm was based on colour and shape detection, however a chosen apple variety developed its colour differently according to the growing stage, therefore an adjusted algorithm had to be developed and tested.

The discussion presented here will concern a whole set of images and will be illustrated with images showing one sample tree of 'Gala', chosen to be representative of the method's result. As seen from the RGB image (Fig. 1a), fruits could not be detected accurately, because the RGB intensity varied greatly according to the images exposure to both sunny and shadow side of the tree. To overcome this problem, in the first step the data of a representative image from each series was divided into three basic planes R, G, B. According to the histogram analysis, the G image was selected for the first stage and the R image for all further stages (Fig. 1b).

In the second stage the image was filtered using a specified size of kernel (3x3 pixels) to remove the remaining noise. Additionally, by applying the low-pass filter 'connectivity-4' two pixels were considered as part of the same object if they were horizontally or vertically adjacent (Fig. 1c).

Once pixels from leaves and fruits were established, in the third stage the differentiation between them proceeded on the binary images (Fig. 1d) by using of two templates. The first elliptical template was chosen to detect as much spherical object as possible, while the majority of square parts (mounting) and elongated objects (leaves, branches) were rejected (Fig. 1e). After that with the second template representing the whole apple fruit of each developing stage, apples were differentiated from other spherical objects. The result of a two stage processing is shown in Figure 1f. As seen, a misidentification between leaves and fruits might occur when capturing images under natural conditions due to the similar illumination of different objects. To overcome this problem the standard morphological characteristics were calculated for each detected object and evaluated according to selected parameters of the four typical classes (Table 1).

**Table 1. Classification parameters of selected objects**

| Parameter | Equation | Apple fruit (whole) | Apple fruit (partly) | Leaf (whole) | Leaf (partly) |
|---|---|---|---|---|---|
| Major axis | $X_{upper\ left} - X_{bottom\ right}$ | * | * | * | * |
| Minor axis | $X_{bottom\ left} - X_{upper\ right}$ | * | * | * | * |
| Area | $\pi$ major axis minor axis | * | * | * | * |
| Perimeter | $\pi \cdot \sqrt{2(majoraxis^2 + minoraxis^2)}$ | * | * | * | * |
| Compactness | $\frac{16\ Area}{Perimeter^2}$ | 1.02-1.06 | 0.52-0.55 | 0.40-0.42 | 0.57-0.59 |
| Elongation | $\frac{(major.axis - minor.axis)}{(major.axis + minor.axis)}$ | 0.08-0.10 | 0.51-0.54 | 0.61-0.63 | 0.22-0.24 |
| LTP (length to perimeter) | $\frac{major.axis}{perimete}$ | 0.30-0.32 | 0.33-0.35 | 0.38-0.39 | 0.36-0 38 |

*selected limits depend on the developing stage

Prior the automatic evaluation classification the system was trained with a given objects separated from a part of the captured images on the same day the evaluation took place. The first class represents the whole apple fruit, the second the part of an apple fruit and two others are the leaf and a part of the leaf, respectively. The applied training parameters are represented in the Table 1. As shown, the most suitable parameters for significant differences between apples and the noise classes were the compactness, elongation and LTP (length to perimeter). Only objects completing the all criteria of borders values for apple fruit 'whole' and apple fruit 'partly' were finally accepted as fruits in the result image (Fig. 1f). The data of objects was later used for calculating the diameter of the fruit according to the pixel/mm proportion and estimating the future yield as already explained by Stajnko et al. (2004).

## Estimation of future yield

The number of fruits and the average diameter of detected fruits on each image were the basis for estimating the current yield. A file with recorded fruit characteristics as well the yield per image was stored for conducting a statistical analysis. For calculating current yield on the image, the following equations were applied:

$$Y_d = \frac{N \cdot 0{,}4059D^{2{,}9602}}{10^6} \qquad (1)$$

where Yt represents the yield per tree in kg, N the number of fruits per tree, D the average value of the longest segment.

The equation is based on a transformed function derived by Welte (1990) and allows a direct calculation of the weight from the fruit's diameter. He showed that during the fruit growing, the relative increase in diameter was proportional to the relative fruit weight increase. In our research for the first four samplings the average fruit yield per tree was calculated on the basis of average fruit's diameter measured manually by the sliding calliper and compared to the estimated yield based image analysis. Contrary, at harvesting the coefficient was calculated between weighted and estimated yield.

For performing the above described algorithms the IMAQ Vision 4.1.1. and Labview 5.0.1. from National Instruments® was used in our investigation. The statistical analyses of manually and by image analysis obtained results were performed using SPSS Package Program.

# RESULTS AND DISCUSSION

## The number of fruits per tree

The number of apple fruits per tree detected by the image analysis and manually counted is presented in the Table 2, 3. As stated earlier the fruit detection algorithm was tested for different abounded apple trees with 12 to 68 fruits. However, because of the dry and hot weather in the summer, the number of fruits slightly decreased in both years from June to end August. Contrary, correlation coefficient (r) is varying from 0.83 to 0.88, depending on different developing stages of fruits. The lowest correlation was obtained in first measurements, on June 22 2002 (r=0.70) and May 26 2003 (r=0.76), while the highest correlation r =0.92 and r= 0.91 was established in both years at harvesting. The reason for the increase of the correlation coefficient values during the maturity period was changes of the fruits' colour and the diameter. Similar observations were reported by Kondo et al. (1998) for robotic harvesting of strawberries and Kataoka et al. (1999) when testing the robot for apple harvesting.

**Table 2. Number of apple fruits in 2002 (N=10)**

| | May 23 | | June 22 | | July 11 | | August 14 | | August 20 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | IA | M | IA | M | IA | M | IA | M | IA |
| **Min** | 14 | 12 | 14 | 16 | 14 | 18 | 14 | 19 | 12 | 14 |
| **Max** | 42 | 46 | 42 | 40 | 42 | 42 | 42 | 43 | 42 | 43 |
| **Mean** | 26.8 | 31 | 26.8 | 28.1 | 26.8 | 29.3 | 26.8 | 29.8 | 24.5 | 27.9 |
| **S.dev.** | 9.9 | 12.1 | 9.9 | 8.4 | 9.9 | 10.1 | 9.5 | 9.8 | 9.7 | 10.9 |
| **CV.** | 37.1 | 39.0 | 37.1 | 29.8 | 37.1 | 3.7 | 35.5 | 32.8 | 39.7 | 38.9 |
| **Corr.coef.** | 0.79* | | 0.70* | | 0.87** | | 0.88* | | 0.93** | |

M ...manually
IA ...image analysis
* $p<0{,}05$
** $p<0{,}001$

**Table 3. Number of apple fruits in 2003 (N=10)**

| | May 26 | | June 26 | | July 9 | | August 8 | | August 28 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | IA | M | IA | M | IA | M | IA | M | IA |
| Min | 24 | 29 | 23 | 22 | 23 | 22 | 23 | 16 | 14 | 14 |
| Max | 50 | 68 | 57 | 68 | 48 | 49 | 48 | 50 | 47 | 49 |
| Mean | 39.7 | 40.7 | 39.7 | 37.8 | 37.6 | 36.5 | 37.6 | 34.0 | 33.6 | 31.6 |
| S.dev. | 11.0 | 12.1 | 11.1 | 13.4 | 9.9 | 10.0 | 9.9 | 10.2 | 12.1 | 12.2 |
| CV. | 27.8 | 29.9 | 27.9 | 35.4 | 26.3 | 27.4 | 26.3 | 29.9 | 35.9 | 38.6 |
| Corr.coef. | 0.76* | | 0.79* | | 0.76* | | 0.89** | | 0.92** | |

## The apple fruit diameters per tree

The average fruits diameters per tree predicted for different developing stages of apple are shown in the Tables 4 and 5. It is clearly shown, that the average fruit diameter per tree was lower than the actual fruit diameters at all developing stages during the vegetation period 2002, while in 2003 it was practically the same. Contrary, to the number of fruits per tree, the correlation coefficient varied from r=0.33 to r=0.80. The reason for lower coefficients lies in the underestimation of the apple fruit's diameter detected by the fruit detection algorithm, which is actually based on the longest segment measurements. Namely, it was shown during the research, that the algorithm was accurate sufficiently, if a whole apple fruit was detected or a part of it was clearly seen. However, leaves, branches and other fruits sometimes hide the edges of fruits, thus lower fruit diameter was measured by image analysis and lower correlation coefficient was obtained. Therefore, it is suggested to develop a more advanced algorithm for calculating the apple diameter and to include a long-term measurement of each variety in the database.

**Table 4. The average diameters of apple fruits (in mm) in 2002 (N=10)**

| | May 23 | | June 22 | | July 11 | | August 14 | | August 20 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | IA | M | IA | M | IA | M | IA | M | IA |
| Min | 20 | 20 | 32 | 30 | 52 | 40 | 67 | 49 | 70 | 55 |
| Max | 59 | 52 | 71 | 40 | 59 | 100 | 79 | 116 | 81 | 85 |
| Mean | 39 | 39 | 51 | 49 | 56 | 57 | 70 | 69 | 78 | 76 |
| S.dev. | 14.7 | 12.0 | 14.7 | 12.6 | 2.2 | 21.4 | 3.5 | 19.9 | 3.3 | 9.9 |
| CV. | 37.6 | 30.8 | 28.8 | 25.7 | 3.9 | 37.5 | 4.9 | 28.8 | 4.2 | 13.0 |
| Corr.coef. | 0.77* | | 0.80* | | 0.78* | | 0.88** | | 0.77* | |

**Table 5. The average diameters of apple fruits (in mm) in 2003 (N=10)**

| | May 26 | | June 26 | | July 9 | | August 8 | | August 28 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | IA | M | IA | M | IA | M | IA | M | IA |
| Min | 37 | 35 | 50 | 49 | 46 | 48 | 71 | 69 | 64 | 65 |
| Max | 48 | 56 | 58 | 64 | 64 | 72 | 80 | 82 | 89 | 88 |
| Mean | 42 | 41 | 54 | 53 | 58 | 58 | 76 | 76 | 79 | 80 |
| S.dev. | 3.4 | 5.9 | 2.7 | 2.9 | 5.7 | 7.8 | 2.9 | 5.2 | 6.1 | 6.8 |
| CV. | 8.1 | 14.3 | 5.0 | 5.6 | 9.9 | 13.4 | 3.8 | 6.8 | 7.8 | 8.5 |
| Corr.coef. | 0.35 | | 0.33 | | 0.75* | | 0.80* | | 0.77* | |

## Estimation of fruit yield

The current mass of fruits per tree was estimated by applying equation 1, whereas the number of fruits and the average fruit diameter from each developing stage were used for estimating the yield. As seen from Table 6 and 7, the average estimated yield per tree was increasing in both years from the end of fruit tinning in May till the harvest in August, however the yield per tree was slightly overestimat-

**Table 6. The apple yield per tree (kg) in 2002 (N=10)**

| | May 23 | | June 22 | | July 11 | | August 14 | | August 20 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | IA | M | IA | M | IA | M | IA | M | IA |
| Min | 0,12 | 0.14 | 0.21 | 0,28 | 0.85 | 0,44 | 1,53 | 0,98 | 3.16 | 1.83 |
| Max | 2.91 | 2,29 | 3,22 | 3.17 | 3,48 | 7.82 | 3.60 | 9.19 | 7,36 | 8.98 |
| Mean | 0.95 | 0.81 | 1.57 | 1.30 | 1.84 | 2.31 | 2.35 | 2.71 | 3.14 | 4.27 |
| S.dev. | 0.82 | 0.69 | 1.55 | 1.02 | 0.73 | 2.29 | 0.66 | 2.45 | 1.43 | 2.37 |
| CV. | 86.3 | 85.8 | 98.7 | 78.5 | 39.7 | 99.1 | 28.1 | 90.4 | 45.6 | 55.5 |
| Corr.coef. | $0.86^{*}$ | | $0.78^{*}$ | | $0.87^{**}$ | | $0.88^{**}$ | | $0.58^{*}$ | |
| Corr.coef.$_{harv}$ | 0.25 | | 0.16 | | 0.08 | | 0.09 | | $0.58^{*}$ | |

**Table 7. The apple yield per tree (kg) in 2003 (N=10)**

| | May 26 | | June 26 | | July 9 | | August 8 | | August 28 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | IA | M | IA | M | IA | M | IA | M | IA |
| Min | 0.65 | 0.57 | 1.47 | 0.92 | 1,98 | 1,23 | 3,72 | 2,83 | 4.20 | 3.34 |
| Max | 1.46 | 1.79 | 3,11 | 3.04 | 3,75 | 4,22 | 7,48 | 6,48 | 9,82 | 8,20 |
| Mean | 0.97 | 0.99 | 2.17 | 1.93 | 2.53 | 2.47 | 5.56 | 4.95 | 7.64 | 5.49 |
| S.dev. | 0.26 | 0.41 | 0.50 | 0.64 | 0.73 | 0.82 | 1.22 | 1.28 | 2.45 | 1.97 |
| CV. | 26.8 | 41.4 | 23.0 | 33.2 | 28.9 | 33.2 | 21.9 | 25.9 | 32.1 | 35.9 |
| Corr.coef. | 0.29 | | $0.64^{*}$ | | $0.84^{*}$ | | $0.66^{*}$ | | $0.70^{*}$ | |
| Corr.coef.$_{harv}$ | 0.06 | | $0 69^{*}$ | | 0.25 | | 0.50 | | $0.70^{*}$ | |

ed in 2002 and underestimated in 2003, as it was the number of fruits on which the calculations based. Consequently, the correlation coefficient between manual measurements and image estimation also varied from the lowest in May 2003 (r=0.28) to the highest in July 2003 (r=0.84).

When representing and comparing the manual measurements with the estimation of the average yield per tree

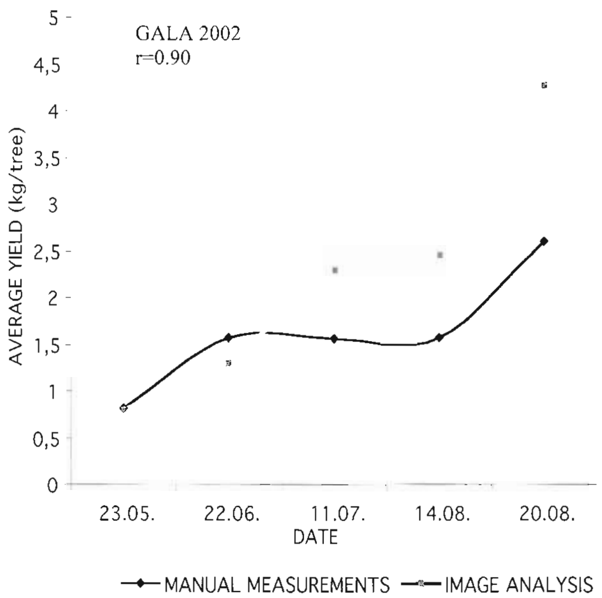


**Fig. 2. Growing curves of the yield development in 2002 estimated by manual measurements and image analysis**

graphically (Fig. 2, 3), almost identical growing curves were estimated in both years. Thus, it could be concluded that the developed algorithm may represent a good tool for the early determination of fruit development and yield estimation.

## CONCLUSION

A new approach for counting apple fruits on trees and estimating the diameter and the current yield under artificial lighting (flash) fruit tree plantation conditions was analysed

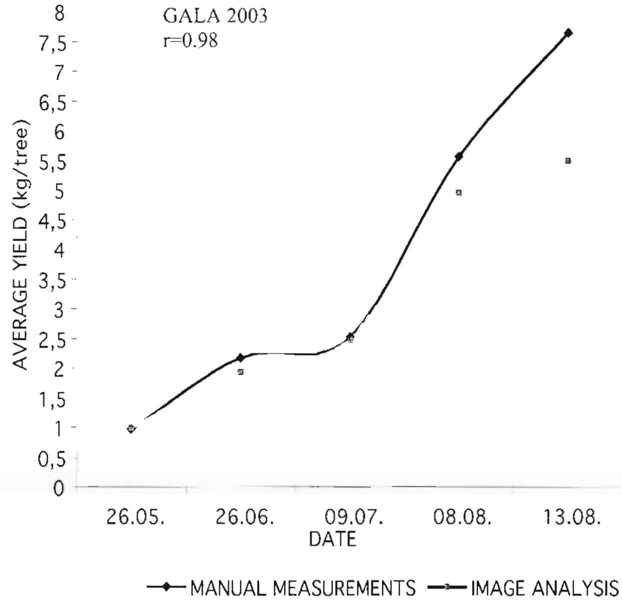


**Fig. 3. Growing curves of the yield development in 2003 estimated by manual measurements and image analysis**

in our research.

The investigated measuring technique based on RGB imaging and analysis procedure was used successfully during the whole growing period of fruits from May to August in 2002 and 2003 in all cases when only a small part of the apple fruit was separated from the background. The system enables faster sampling and evaluation of larger plantation than it is possible with the current manual method. However, it was not always able to distinguish between fruits and leaves growing deep in the tree-crown.

Therefore, future work should be focused on improving the algorithm by implementing the shape recognition procedure to the algorithm, so that it would be possible to detect also partially hidden spherical objects by obtaining a set of pixels belonging to the boundaries of apples.

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