Denis Stajnko[1], Tatjana Unuk[1], Nina Tojnko[1], Simon Kolmanič[2] **Original scientific paper**

Automated procedure for early prediction of apple yield in orchardse

Abstract
Procedure for early forecasting of apple yields in Slovenian orchards is presented with the help of a modern application that works in the Android environment and uses a fast 5G transmission network. To recognize fruits in images of 'Golden delicious' trees, we used the YOLO pre-learning network, which is based on convolutional neural networks and regression techniques to determine the position of apples in the image. To model the fruit yield, specific cultivar-adjusted growth curve is used, which makes it possible to predict fruit mass from the current and expected fruit diameter and the ratio between diameter and mass. The procedure was tested on a series of 20 images captured from six-years-old orchard revealing on average 71.84% accuracy in fruits counting, 108.27% accuracy in diameter calculating and 97.90% accuracy in yield forecasting. With the first estimation, we have shown that the automated method for yield forecasting is an excellent tool for accurately estimating the yield of an individual plot so we will continue to upgrade it in the future.
Keywords: *apple trees, prediction, thickness, model, algorithm*

Introduction

Apple production in the EU 27 was between 10.5 and 13.0 million tons in the last five years, which means that the apple tree is still one of the most important deciduous fruit species (Lieberz and Luxbacher, 2023). However, climate change and related natural disasters are increasingly reflected in large interannual fluctuations in the amount of crops, so that for the period 2021/2022 in individual countries they amounted to between -28% and +33 %. Such uncertainty presents major problems in the planning of harvesting and storage and, as a rule, affects the creation of seasonal and annual market prices (Lieberz and Sawatzki, 2022).

Due to the mitigation of larger interannual price fluctuations, the effective forecasting of the apple harvest has always been a unique challenge for both scientific and research organizations as well as for individual fruit growers, fruit growers' organizations as well as traders. Since the beginning of the 1980s, thanks to the increasing performance of computers, apple yield modelling has become particularly widespread (Winter, 1986; Welte, 1990), as it has been possible to replace large-scale field experiments with fruit race simulation from flowering to ripening (Hester and Cacho, 2003).

1 Prof. dr. sc. ***Denis Stajnko****, prof. dr.* ***Tatjana Unuk****,* ***Nina Tojnko****, M.Sc., University of Maribor, Faculty of Agriculture and Life Sciences, Pivola 10, 2311 Hoče, Slovenia*
2 Doc. dr. ***Simon Kolmanič****, University of Maribor, Faculty of Electrical Engineering and Computer Science, Smetanova 17, 2000 Maribor, Slovenia*
Corresponding author: denis.stajnko@um.si

The time-consuming manual counting has stimulated the development of the 'image analysis method', which, with the help of visualization of tree crowns in orchards, enables the use of computer processing algorithms adapted to the recognition and counting of fruits of different varieties of apples and pears. In Slovenia, in the last two decades, the image processing method, which was first presented to the public by Stajnko et al. (2004), has been used to forecast the yield of apples and pears. The computer code is written in the Labview® software environment, the IMAQ Vision® package, and is based on the processing and analysis of digital images captured in the orchards of Slovenia, and in most samples accurately predicts the expected yield.

The built-in algorithm calculates the mass of the crop per hectare at harvest from the number of fruits counted in the images and the expected diameter of the fruits at harvest, estimated with the help of long-term growth curves. Since when predicting the yield using the image analysis method, there were still a small proportion of deviations, which we associate with errors in the recognition of fruits in images, in the past we wanted to include newer methods of fruit recognition in new algorithms and by using of more modern artificial logic, such as decision trees, but the Labview® programming environment was not suitable for newer mobile operating systems. With the advent of smartphones and fast 5G internet connections from the beginning of the 2020s, the method of image processing has also become more and more outdated due to the way data is captured and processed, as it still requires the transfer of images and their processing in laboratories on algorithms installed on personal computers.

In the present article, we first want to present the functionality of the procedures, which works in the Android environment on tablets and smartphones, for automated early forecasting of the apple yield in orchards. In the second part, we compare the accuracy of the new procedure with the older algorithm and the measured compartment on experimental plot planted with 'Golden delicious' variety.

Materials and methods

Experimental design

In August 2023, twenty apple trees were examined in the Faculty's six-year-old apple orchard, located at Estate 'Pohorski dvor' (46.409.794 Lat. and 15.996.108 Long.). Every tree was photographed from a distance of 1.5 m with a smart phone together with a purple/blue coloured tennis ball for the purposes of evaluating the novel algorithm as well as image analysis in the Labview software environment (Figure 1). At the same time, the number of fruits on individual tree was counted and the current diameter of 10 randomly selected fruits were measured by using a digital calliper. Each image was first processed in the laboratory according to already known procedures and then used to calibrate the new procedure.

Figure 1: Sample of RGB image with blue tennis ball hanging in the middle of 'Golden delicious' apple tree
Slika 1: Uzorci RGB slika s plavom teniskom lopticom koja visi u sredini 'Golden delicious' stabla

Algorithm

To detect apples in images, we used the YOLO (You Look Only Once) neural network (Du, 2018; Liu et al., 2018), which is an established method for object detection and is successfully used in many fields. The algorithm surrounds the searched object in the image with a square and attributes to it the probability of matching with the searched object. The advantage of the YOLO method over other neural networks is that it finds all the objects in the image with a single pass. This makes the method extremely fast and also suitable for real-time detection of objects. The speed of operation of the method allowed us to use ten images of the orchard for the prediction, and to carry out additional activities to improve the perception. Although more of them could be easily processed with the aforementioned method, the main bottleneck is the transfer of photos from the orchard to the server where the apple recognition algorithm works. Our network that we used to detect apples was pre-trained. As a result, we saved a lot of time, as we did not need to compile a training set, where we had to manually mark the apples on many images of apple trees, so that the network could properly calibrate the neuron weights during the learning phase and thus enable apple recognition. Although such an approach allowed us to start with the perception in the first place, the choice of an already learned neural network also had some disadvantages. The first was that in some cases, when there were many apples in close proximity in the image, in addition to individual apples, it marked the entire group as a hit, as we can see in Figure 2.

Figure 2: Mislabeling a group of apples as an extra large apple
Slika 2: Pogrešno označavanje grupe jabuka kao posebno velike jabuke

Another problem that needed to be solved was the poorer perception of apples in poor lighting, where there was little difference in colour between the leaves and the fruit. We solved this by examining each image twice, at different resolutions and with an added twist. With this, we significantly improved the reliability of the detection, as the network was able to find additional apples in the images created in this way, which would otherwise have remained undetected. Of course, care had to be taken not to count the same apples twice. We prevented this by creating a new final list based on the list of detected apples in both images. We first inserted all detected apples from the first image into this list, and then added detected apples from the second image, but only if it was not already found in the first image. We determined this using the relative position of the apple in relation to its neighbours. We also used list building to find the reference object in the image. It was a tennis ball of blue colour, which had to be hung on the apple tree before taking pictures (Figure 3).

Since we wanted the detection of apples to work completely autonomously, that is, without the help of the user, we also had to find the reference object in the image using the YOLO network. Due to the round shape of the reference object, it perceived it as an apple. Thus, it was necessary to review the list of detected apples in the image and remove the one whose colour was closest to the selected colour of the reference object. For this process to work, the colour of the reference object must contrast as much as possible with the other colours in the image. After we have found the reference object, we calculate the diameters of all found apples with its help.

Figure 3: Detection of ‚Golden delicious' apples, together with a reference object
Slika 3: Detekcija 'Golden delicious' jabuka, zajedno s referentnim objektom

Growth curves for calculating fruit weight

The models of growth curves that we used in the new application were accurately presented by Stajnko et al. (2012), so here we summarize only the equation for calculating the growth of fruit diameter during the time from flowering to harvest:

$$D(t) = 3{,}5 + \alpha \cdot (1 - e^{-\beta t})^{\gamma} \qquad (1)$$

where:

D(t) – diameter of the fruit (mm),
t – time from full flowering till harverst (days),
α + 3,5 – maximal teoretical diameter of the fruit (mm),
β, γ – factors influencing by the shape of the fruit

After obtaining the fruit diameter growth equations, in the second step we calculated the weight of the fruit from the diameter according to the equation:

$$Y_d = \frac{0{,}4059 \times D^{2{,}9602}}{1000} \qquad (2)$$

where:

Y_d ...fruit weight (g)
D ...diameter of the fruit (mm)

For data processing, we used the statistical program IBM SPSS Statistisc 22.0, with which we evaluated the different models and the predicted yield using the ‚pair sample test' method at $p<0.05$.

Results

Advantages of the new application

The algorithms used make it possible to easily capture images in orchards with the help of a mobile application, which then sends images to the server for processing. Due to the speed of the YOLO network, processing is fast, and the calculated yield forecast is then displayed to the user by the mobile application. The forecast always depends on the trees we choose for photography, if they are not representative, the forecast may differ from the weighted crop, so the user has the option to cancel the forecast and repeat the recording process. If the user accepts the prediction, it is automatically entered into the orchard activity logging application to which the mobile application is connected. On the other hand, the mobile application obtains from the online platform the necessary information about the variety, the number of trees in the orchard, the distance between trees in a row and between rows, and other data stored in the Register of Agricultural Holdings.

In order to use the mobile application for early crop forecasting, the user must have an active account in the application for logging activity in the orchard. The user thus logs into the mobile application with a username and password, and then selects the plantation for which the forecast will be carried out from the list of plantations for which he keeps statistics. This is necessary, as several plantations can be located on an individual GERK, but we do not have information about where exactly they are located on the GERK, and it is also necessary to select the height of the trees, since we do not keep this information in the Register of Agricultural Holdings either. After entering these two data, the application only asks for photos of the five trees in the orchard and calculates a forecast based on this. Using the application is simple and thus suitable for fruit growers of all ages, using mobile phones does not require any additional equipment and thus demonstrates the advantages of digitization in practice.

Accuracy of algorithm

The estimated number of apple fruits per tree by the YOLO algorithm as well as manually counted fruits is represented in the Table 1. As seen, on the average 27.47 fruits were manually counted and 19.74 were detected by automated procedure, respectively, meaning that an average index of 71.84% was calculated. In all samples the number of fruits was underestimated due to several reasons. The main reasons represented the leaves and branches, which hide or cover the fruits. In some samples the algorithm was not able to distinguish specific fruits because they were growing in the clusters.

On the other hand, whenever evaluating the average fruit's diameter per tree 70.90 mm was manually measured and 76.76 mm was estimated by automated procedure meaning that 8.27% bigger diameter was calculated. It is assumed that selected long-years growing curves did not fit enough to the particular year of sampling. Still, it is an excellent results given that a lot of fruits were partly hidden or overlapped with other obstacles (leaves braches).

The forecasting of yield per tree is most challenging task, because beside the number of fruits the estimation of apple diameter at harvest is imprecise data in procedure. Namely, it is based on the average growth curve and the date of T-stage, which are never the same from year to year. Despite this fact, on average the estimated yield per tree was for 0.09 kg lower than weighted one (Index 97.90%), however, when looking in details the main reason for big variability between specific trees lies in the underestimated number of fruits.

Table 1: The comparison between manual and estimated fruits characteristics
Tablica 1: Usporedba ručno izmjerenih i procijenjenih karakteristika plodova

	Number of fruits			Diameter (mm)			Yield (kg/tree)		
Image	Manual	YOLO	Index % (M/Y)	Manual	YOLO	Index % (M/Y)	Weighted	Estimated YOLO	Index % (W/Y)
1	14	9	64.29	79	74	93.54	2.6	3.9	66.67
2	26	20	76.92	71	75	93.70	3.9	3.58	108.94
3	21	16	76.19	74	80	91.87	3.58	2.82	126.95
4	20	9	45.00	69	76	89.16	2.82	5.62	50.18
5	41	21	51.22	69	82	81.60	5.62	4.04	139.11
6	26	27	103.85	70	75	93.39	4.04	5.92	68.24
7	33	26	78.79	68	73	92.71	5.92	2.62	225.95
8	17	18	105.88	67	77	85.04	2.62	3.12	83.97
9	28	17	60.71	72	76	94.24	3.12	6.82	45.75
10	42	29	69.05	70	79	86.66	6.82	4.104	166.18
11	14	9	64.29	79	74	93.54	2.6	3.9	66.67
12	26	20	76.92	71	75	93.70	3.9	3.58	108.94
13	21	16	76.19	74	80	91.87	3.58	2.82	126.95
14	20	9	45.00	69	76	89.16	2.82	5.62	50.18
15	41	21	51.22	69	82	81.60	5.62	4.04	139.11
16	26	27	103.85	70	75	93.39	4.04	5.92	68.24
17	33	26	78.79	68	73	92.71	5.92	2.62	225.95
18	17	18	105.88	67	77	85.04	2.62	3.12	83.97
19	28	17	60.71	72	76	94.24	3.12	6.82	45.75
20	42	29	69.05	70	79	86.66	6.82	4.104	166.18
Average	27.47	19.74	71.84	70.90	76.76	108.27	4.18	4.27	97.90

Conclusions

A new approach for modelling of apple fruit development and estimation of the yield at harvest under orchard conditions was researched on a series of images with 'Golden delicious' tree apples. Based on the captured RGB images via smart phone and grown trough the several analysis procedures including YOLO network, processing is fast. The first calculation of yield forecast shows a great possibility for modelling of yield development in the 'Golden delicious' variety during the vegetative period. However, future work should be developing algorithm, so it is able to estimate the yield of apple tree in specific apple plantation.

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Automatizirani postupak ranog predviđanja prinosa jabuka u voćnjacima

Sažetak

Prikazan je postupak ranog predviđanja prinosa jabuka u slovenskim voćnjacima uz pomoć moderne aplikacije koja radi u Android okruženju i koristi brzu 5G prijenosnu mrežu. Za prepoznavanje plodova na slikama sorte ‚Golden delicious' koristili smo YOLO mrežu prethodnog učenja koja se temelji na konvolucijskim neuronskim mrežama i regresijskim tehnikama za određivanje položaja jabuka na slici. Za modeliranje prinosa ploda koristi se specifična krivulja rasta prilagođena sorti. koja omogućuje predviđanje mase ploda iz trenutnog i očekivanog promjera ploda te omjera promjera i mase. Postupak je testiran na nizu slika snimljenih u šest godina starom voćnjaku ‚Golden delicious' otkrivajući 71,64 % točnost u brojanju plodova, 91,73 % točnost u izračunavanju promjera i 72,65 % točnost u predviđanju prinosa. Već prvim testovima pokazali smo da je automatizirana metoda za prognozu prinosa izvrstan alat za točnu procjenu prinosa pojedine parcele pa ćemo je i u budućnosti nadograđivati.

Ključne riječi: *jabuka, model, debljina, prognoza*