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Automated Assessment and Mapping of Grape Quality through Image-based Color Analysis

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Abstract: The harvest operation for table-grapes and fresh market horticultural fruits is a large and expensive logistical challenge with the choice of harvest dates and locations playing a crucial role in determining the quality of the yield and in determining the efficiency and productivity gain of the entire operation. The choice of harvest dates and locations, particularly in red varieties, is planned based upon the development of the color of the grape clusters. The traditional process to evaluate the amount of ripe, fully-colored fruit is visual assessment, which is subjective and prone to errors. The number of locations where a grower will evaluate the fruit development is statistically insufficient given the size of commercial vineyards and the variability in the color development. Therefore, an automated approach for evaluating color development is desirable. In this paper, we use a vision-based system to collect images of the fruit zone in a vineyard. We then use color image analysis to grade and predict the color development of grape clusters in the vineyard. Using our approach we are able to generate spatial maps of the vineyard showing the current and predicted distribution of color development. Our imaging measurement system achieves R^2 correlation values of $0.42-0.56$ against human measurements. We our able to predict the color development to within 5% average absolute error of the imaging measurements. The prediction of spatial maps is important from the perspective of selective harvesting as it allows the precise targeting of productive zones during the harvest operation. To the best of our knowledge generation of these spatial maps that represent the current and predicted state of the color development of an entire vineyard block, before harvest and in high resolution, is a first of its kind.

Keywords: Computer Vision, Automation, Color Analysis, Precision Viticulture, Precision Harvest.

1. INTRODUCTION

Grape harvest operation is a large and expensive logistical challenge and hence requires cost effective solutions. The choice of harvest dates determines the quality of the yield. Grapes once harvested do not ripen and therefore must not be harvested when immature. While, on the other hand leaving the fruit on the vines for too long results in either the berries shattering, being damaged by wildlife and insects, or breaking down due to rot. Another important factor is the choice of harvest locations. In commercial vineyards, different regions mature at different rates. Identifying and targeting these zones enhances the efficiency and productivity gain of the harvest operation.

The traditional process to evaluate the amount of ripe, fully-colored, fruit is for a grower to visually assess color development at a set of locations in their vineyard. For large commercial vineyards, its economically intractable to exhaustively evaluate the entire field owing to the labour intensive nature of the work. The number of locations where a grower will evaluate the fruit development is statistically insufficient. Moreover, the evaluation process is subjective according to the person performing the visual evaluation. Therefore, an automated approach for evaluation of color development is desirable. Over the past few years, our research group has focused on developing a vision-based system (Fig. 1a) for automatic fruit-detection and high resolution yield-estimation. The images captured by our system are processed for assessing color development and grading of fruits (Fig. 1b).

The main contributions of this paper are

(1) Use of color analysis for categorizing clusters of grapes into different stages of color development.
(2) Generating spatial maps of the vineyard showing distribution of color development
(3) Computing the rate of color development and using this to make future predictions of the spatial map

The approach presented in this paper has a clear application in the area of Precision Viticulture. The spatial maps can be used for differential management of vineyards to improve the color development in areas of low productivity. The maps also enable selective harvesting to optimize quality and increase harvest efficiency.

The rest of the paper is organized as follows. Section 2 describes the related work on color analysis used in agriculture. Section 3 describes our system for evaluating grape cluster color. Section 4 describes the sensor setup, the

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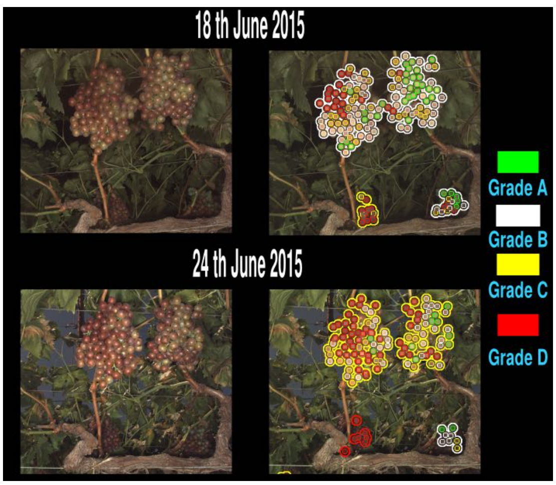
(a)



(b)

Fig. 1. An overview of the Yield Mapping System (a) Imaging Unit in Vineyard – consisting of stereo cameras and a pair of flashes for capturing high resolution images. (b) Left: Raw images of clusters on the 18th and 24th June 2015. Right: Image automatically processed to detect clusters and evaluate color development. Berries that are well-colored are highlighted by a red square. Clusters classified as having sufficient level of well-colored berries are highlighted with red contour. Those berries and clusters that are deemed not well colored are highlighted yellow.

data-set and the experimental setup. Results are presented in Section 5 and conclusion in Section 6.

2. RELATED WORK

The use of image analysis of fruit images has been widely employed in automating the fruit packing industry [Zhang et al., 2014]. Rodríguez-Pulido et al. [2012] presents a method of estimating the ripeness of grape berries by performing histogram thresholding on CIELAB and HSI color space of grape images.The structured conditions present in these settings make it easy for computer systems to perform inspection and sorting with high accuracy. However, performing such operations in the unstructured agricultural fields present a plethora of issues such as distinguishing fruit from similar colored foliage, dealing with occlusions and large variations in lighting conditions.

[Pothen and Nuske, 2016] presents a method that uses fruit texture for detection of berries out in the field. [Font et al., 2015, Reis et al., 2012] describe methods of using color analysis for the detection of grapes. In [Portalés and Ribes-Gómez, 2015], the authors present a portable vision system that performs preliminary quality assessment of grapes in the field right after they have been harvested. Bramley et al. [2011] use a modified Multiplex sensor, which is a flurosence-based optical sensor, mounted over the discharge conveyor of a harvestor to determine the anthocyanin content of the grapes and use this information to generate spatial maps of grape maturity. However, the above methods do not address the problem of fruit quality analysis in the field before harvest.

[Santos et al., 2012] presents an approach that uses NIR-based imagery to measure and generate map grape quality across a vineyard. [Martinez-Casasnovas et al., 2012] analyse the use of NDVI maps to delineate areas based on wine grape properties in the vineyard for selective harvesting. However, these methods do not track the color development of the grape clusters, which is an important parameter for assessing quality of table grapes. Moreover, the grape clusters are not classified into appropriate quality grades.

In this paper, we present a method that uses color analysis of berry clusters to classify clusters into four different grades and generate high resolution spatial maps of vineyards.

3. APPROACH

Our method is based on using color image analysis to grade and predict the color development of grape clusters in the vineyard. Using a high-resolution color camera, paired with a high-power, fast, xenon flash we collect images of the fruit zone. The images are processed to identify and grade grape clusters based on their stage of color development. The grape clusters are combined to create a spatial map of the entire vineyard. Using images collected over different dates, we compute the rate of color development, which is then used to make future predictions.

3.1 Grape Detection

The first stage of image processing is to detect the locations of berries in each image. We have developed an image processing algorithm [Nuske et al., 2011, 2014b] that can detect berries using the three visual properties of a grape - the color, the shape and the surface shading. Neighboring berries are then grouped into clusters. In [Nuske et al., 2011, 2014a,b] we have shown that the berry counts collected from the images is an accurate measure of yield.

3.2 Color Extraction and Grading

Alg. 1 illustrates the steps for color extraction and grading of berry clusters. Once we have detected the berries, we extract a measurement of color at each berry location using a color transform from the input RGB image. We desire a color space with a uniform spread of the transformed colors to aid assessing grape clusters, and more importantly, we require a color space that is invariant to spectrally uniform illumination change. The HSV color space meets all of the above criteria.

Robustness and invariance to illumination change is attained by using the H-layer in the HSV colorspace, as the H-layer encodes only the color and not the intensity information in the image. We compute the average H