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Automated Measurement of Berry Size in Images ⋆

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Abstract: Knowledge on berry size in grape vineyards can be a great asset for growers to help manage their crop whether for yield assessment or grape quality control. Having the ability to size berries of an entire field would allow growers to effectively monitor their vineyards at various stages of the growing season. Manual methods for determining berry size distribution of an entire field can be time consuming and rely on small sample sets which can lead to inaccuracies. This paper introduces an automated imaging system that measures diameter of grapes for every vine in an entire vineyard and generates a comprehensive map showing berry size variability which until now has not been available to growers. Believed to be the first example of mapping berry size across commercial vineyard blocks, this system uses computer vision techniques to locate and size the berries identifying submillimeter berry diameter differences. Maps of variability in berry size are shown to correlate with canopy size and yield. Diameter estimations are found to measure within 6% of manual measurements and a strong correlation is seen between estimated berry sizes and actual berry weights with $r^2 = 0.96$.

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1. INTRODUCTION

The ability to quantify grapevine traits can provide valuable knowledge for growers, allowing them to take better control of their fields, and to more effectively meet demands of the viticulture industry. One such characteristic is berry size which can be important for growers to posses during the growing season, not only for monitoring grape quality and composition, but also determining the current state of vineyard growth. The influence of berry size on wine quality has been a topic of great discussion as to whether smaller berries and yield can affect wine quality (Matthews and Nuzzo 2007; Barbagallo et al 2011). Whether berry size directly affects wine quality or rather the viticultural practices on vines is the main influencer, data on berry size can allow growers to apply the necessary techniques to craft the right balance between final yield and berry composition. Prior to veraison, rapid berry growth is characterized by cell division and cell enlargement (Dokoozlian 2000); water stress on vines during this time has been shown to stall berry growth (Keller et al 2006) and early water deficit from flowering to veraison can result in an irreversible decrease in cell volume (Ojeda et al 2001). The result in berry size due to these changes, whether intentional or not, indicate that monitoring berry growth can be important during this stage of development.

Data on berry size can be a tool to measure variability in the field. Identifying these variabilities can enable precision management in order to increase uniformity and distribute resources and labor in areas that need closer monitoring.

Fig. 1. Vehicle mounted imaging system(top) and sample images of estimated grape diameters for Cabernet Sauvignon(bottom-left) and Petite Syrah(bottom-right)

One example can be seen in canopy management; as growers seek to better control the quality and quantity of their crop, canopy management practices becomes an essential factor in reaching their target outcome. A novel

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irrigation practice proposed by Sanchez et al. (2014) introduces variable rate irrigiation(VRI) to compensate for soil variations within a vineyard in order to optimize for fruit yield, control canopy development variability, and conserve water usage. VRI resulted in an overall decrease in spatial variability in a 4.05-ha rectangular area as viewed by canopy sensor data. Having a vineyard map of berry size variations can be one way to verify whether canopy management practices are producing the desired outcome on the fruits.

Ideally a mechanism would be needed to monitor an entire field and get frequent measurements of grape sizes during the growing season. The developed methods in this paper provide a non-destructive approach for finding the diameter of grapes in metric units using computer vision techniques. Two different algorithms are used to measure the diameter of grapes; one for grapes that reflect a shiny bright center and the other for matte grapes. This is due to the observation that when light is shined on different grape varieties the light reflectance is varied. Fig. 1 shows an example where Petite Syrah grapes reflect a shiny center whereas Cabernet Sauvignon are more matte; the imaging system is automated to choose the algorithms accordingly. These two grape types were chosen as they provide good texture variety and are also two popular wine grapes. The algorithms are applied in a vineyard using a stereo imaging system that can be mounted onto a tractor/UTV, constantly taking images while driving through each row in the field. A sample of the images are used to manually find the diameter of grapes as ground truth data to validate the diameter estimation algorithms. Furthermore, the algorithms are applied in a controlled setting to size clusters of grapes cut from several vines in order to compare against yield measurements.

In the field environment once all images are collected and processed, a map of berry diameters is generated for the entire vineyard. The amount of processed data for generating the maps is significant and comprehensive, comprising of several 100,000 images for more than 10,000 vines in order to most accrurately reflect the observed vineyard in its entirety. As a result, regions of diameter variability achieved from these maps are then shown to correlate with the same regions of canopy size and yield.

2. RELATED WORK

Numerous approaches for measuring berry size have focused on pulling off berries from clusters, using image processing to segment individual grapes, and finding their diameters. Tardaguila et al. (2012) sampled 100 berries showing strong correlation between berry size and weight with r^2=0.96 and 0.97. Kicherer et al. (2013) introduced BAT(Berry Analysis Tool) which uses a DSLR camera to take images of individual grapes laid down on a perforated metal plate. It can accurately measure berry diameters with r^2=0.96 to actual hand measurements, giving an overestimation of only 0.3 mm in a laboratory setting.

More recent work by Liu et al. (2013) attempted to predict weight of entire grape bunches using numerous metrics such as volume, pixel area, perimeter, berry number, and berry size. Visible pixel(bunch area) resulted in the most accurate predictor of bunch yield with a 7.07% error in a controlled setting. Other works by Diago et al. (2014) accurately predict weight of a cluster(up to 95%) in a controlled lighting environment by taking multiple images of the cluster at different viewpoints. Roscher et al. (2014) present a five step framework for detecting and sizing berries; pixel measurements are converted to metric units using a known structure but they recognize that a stereo camera system can help to further automate this process.

In this paper berries are detected and sized for entire vineyards without destemming or destructive sampling. The algorithms are optimized for field conditions, being invariant of distance from camera to berries and outdoor lighting. And finally the stereo camera system is automated, taking as input numerous images and presenting the compiled data to growers in a way that is meaningful in order to help with precision management.

3. APPROACH

3.1 Vehicle Mounted Machine Vision System

The imaging system used to detect and size grapes is a sideways-facing stereo camera mounted onto a vehicle and driven through each row of a vineyard. The two Point Grey 9.1 megapixel cameras have a baseline separation of 90mm and global shutter in order to capture still images as the vehicle is moving. Traveling at 5 feet per second the cameras and a high intensity xenon flash are triggered at 5Hz to take images; the GPS coordinates at each trigger is also recorded automatically by the system. Once all images are collected, the algorithms for estimating grape diameters are automated to step through each image and size the berries. This setup can be seen in fig. 1 and a sample field image with estimated grape diameters in fig. 2. Only the median diameter in each image is used for generating the final berry size variability map; this eliminates any outliers that may have occurred during the grape detection or sizing process.

Fig. 2. Cabernet Sauvignon field image with marked berry circumferences using estimated diameters

3.2 Berry Detection And Diameter Estimation

The berry detection algorithm used is from the three step process described in Nuske et al. (2014) where image keypoints are first detected for potential berry locations, followed by classification of keypoints into *berry* or *not-berry*, and finally grouping of neighboring berries together.

To find the metric diameter of grapes in images first an image patch is created of each detected grape in order to

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