A Survey of Computer Vision Methods for Counting Fruits and Yield Prediction

Anisha Syal[1]
[1]Student, CSE Department, ASET, Amity University
Noida, Uttar Pradesh, India
anishasyal@gmail.com

Divya Garg[2]
[2]Student, CSE Department, ASET,Amity University
Noida, Uttar Pradesh, India
divyagarg1210@gmail.com

Shanu Sharma[3]
[3]Assistant Professor, CSE Department, ASET, Amity University
Noida, Uttar Pradesh, India
shanu.sharma1611@gmail.com

Abstract- In Agriculture the automatic methods for counting the number of fruits play a critical role in crop management. In this paper a review of previous studies and systems to count the number of fruits on trees and their yield estimation is performed. The various computer vision and optimization techniques are presented to automate the process of counting fruits. Further the main features and drawbacks of the previous systems in this area are summarized in this paper.

Keywords – Computer Vision, Fruit Localization, Segmentation, Color and Shape Analysis

1. INTRODUCTION

Image processing has been proved to be effective tool for analysis in various fields and applications. Image analysis based automated counting approaches can be found in many fields such as, medical imaging, horticulture and crop industry & soil research, they show the efficacy of automated counting systems, which are sufficiently reliable, consistent, fast and also more convenient than manual counting. Many times expert advice may not be affordable, majority times the availability of expert and their services may consume time. Image processing along with availability of communication network can change the situation of getting the expert advice well within time and at affordable cost.

With the advent of mechanization of agriculture and a trend towards larger equipment, farmers were able to cultivate very large areas, but many continued to treat their larger fields as a single management unit, thus ignoring variability found within a specific field. Image processing technique has been proved as effective machine vision system for agriculture domain. Imaging techniques with different spectrum such as Infrared, hyper spectral imaging, X-ray were useful in determining the vegetation indices, canopy measurement, irrigated land mapping etc with greater accuracies. Various Computer Vision Techniques are used for precision farming, which is an emerging technology that allows farmers to reduce costs through efficient and effective application of crop inputs for within-field variability in characteristics like soil fertility and weed populations.

A. Precision Agriculture and Yield Mapping

Reducing input costs, minimizing work time, increasing yield, and improving crop quality to boost profit margin are the basic goals for any agricultural firm to compete in domestic and global markets. With high levels of mechanization in crop production, crops are managed based on units such as blocks rather than individual units.

Precision agriculture is a management philosophy that responds to spatial variability found on agricultural landscapes. Steps involving precision agriculture include determining yield variability in a field, determining its cause, deciding on possible solutions based on economic justification, implementing new techniques and repeating the procedure in a cyclic approach. Precision agriculture techniques could be used to improve economic and environmental sustainability in crop production.

Among precision agriculture technologies, yield mapping is the first step to implement site-specific crop management on a specific field. A yield mapping system measures and records the amount of crop harvested at any point in the field along with the position of the harvesting system. This collected data could be used to produce a yield map using mapping software. Yield maps are useful resources to identify variabilities within a field. Variability in an agricultural field is due to man-made or natural sources. A natural variability may be due to seasonal change in weather pattern or rainfall over several years. Examples of man-made variabilities include improper distribution of irrigation/drainage facilities for field and excessive/deficit application of farm inputs

Numerous yield monitoring and yield mapping systems have been widely researched and commercialized for various crops over the last one and a half decades. Yield mapping during grain harvesting (Schueller and Bae, 1987; Searcy et al., 1989) has been extensively studied and adopted. Examples of yield mapping for other crops include cotton (Wilkerson et al., 1994; Roades et al., 2000), potatoes (Campbell et al., 1994), tomatoes (Pelletier and Upadhyaya, 1999), and silage (Lee et al., 2002). Being able to evaluate the entire farm graphically, in an encapsulated picture, with respect to yield and other associated field characteristics would tremendously help farmers to more intimately know their field and thus help them to make important decisions in an efficient manner.

B. Need of Automated Yield Mapping in Agriculture

Harvest estimation has importance to the industry in planning market needs and resources, such as crop insurance purposes, packing materials, planning harvest and employees. Furthermore the industry needs to pre-book tractors, trucks and ships, estimate cash-flow budget, plan delivery estimates to ensure a faster turnaround to lessen wastage of time and resources. Accurate, early estimation of grain yield is an important skill/task.

Currently, contractors are used to count the fruit manually. Then the manual counts are used to estimate the harvest. Around $300,000 to $500,000 is spent on manual counting per year for a typical pack house. Moreover, many other cost and overheads have to be taken into account, such as, Combine overhead, which includes depreciation, interest, insurance, housing, and repair charges on the combine**.** Platform overhead costs include depreciation, interest, insurance, housing, and repair charges on the grain platform and corn head. Fuel costs are based on diesel fuel. Lubrication is 10 percent of fuel cost. Labor costs are based on per hour labor charge. Labor time is 10 percent more than combine operating time.

Additionally, there are issues with the accuracy of manual counts due to the higher number of fruits and the exhaustion from continuous and repeated work. Because of the large scale of production, even a 10% error in estimation is a significant loss to the industry. If overestimated, the money on pre-ordering ships and trucks will be lost and another large investment is potentially blocked due to excess packing. If underestimated, the insufficient pickers, packers, packing material and insufficient time for ordering ships can require a bulk sale of products at much lower price. Having a robust automated counting technique facilitates a fast, consistent and convenient way of counting fruits. This further saves the money spent on manual counting as well as the loss due to erroneous estimations.

II. REVIEW OF COMPUTER VISION METHODS FOR FRUIT COUNTING AND YIELD

The problem of identifying the total number of fruits on trees and plants has long been of interest in agricultural crop estimation work. Till now, many studies were conducted to develop various fruit and vegetables detection systems using computer vision and image processing techniques. Researchers have been still working on design, development and deployment of an automatic system for rapid and better yield estimation for various agricultural crops. A wildly adopted solution to automated fruit yield estimation is to use computer vision to detect and count fruit on trees.

Computer vision is the construction of explicit and meaningful descriptions of physical objects from images. Images can be produced by a variety of physical devices, including still and video cameras, x-ray devices, electron microscopes, radar, and ultrasound, and used for a variety of purposes, including entertainment, medical, business (e.g. documents), industrial, military, civil (e.g. traffic), security, and scientific. The goal in each case is for an observer, human or machine, to extract useful information about the scene being imaged. Digital image processing allows one to enhance image features of interest while attenuating detail irrelevant to a given application, and then extract useful information about the scene from the enhanced image. Image processing operations can be roughly divided into three major categories, Image Compression, Image Enhancement and Restoration, and Measurement Extraction. Image defects which could be caused by the digitization process or by faults in the imaging set-up (for example, bad lighting) can be corrected using Image Enhancement techniques. Once the image is in good condition, the Measurement Extraction operations can be used to obtain useful information from the image.

Yield prediction in fruit orchards would enable precision agriculture in terms of in-time estimates of volume flows of fruit, leasing of fruit bins, planning storage space, fruit store management, labor hire for fruit picking, booking grading facilities and transport equipment as well as trade and retail orders three months ahead of harvest. Crop yield estimation is an important task in apple orchard management. Accurate yield prediction helps growers improve fruit quality and reduce operating cost by making better decisions on intensity of fruit thinning and size of the harvest labor force. It benefits the packing industry as well, because managers can use estimation results to optimize packing and storage capacity.

Machine vision offers the best potential to automatically extract, identify, and count target plants, based on color, shape, and textural features. There are many optimization techniques that may offer more options in results and accuracy, e.g. Neural Network and Support Vector machines. However there are challenges in developing robust, automated counting techniques and they are unique to the specific problem. Some of the challenges for counting are uneven illumination, noise, occluded objects and clumped objects.

In order to overcome practical hazards such as inaccuracies and inefficiencies due to various reasons, yield estimation and counting algorithms for counting number of fruits are analyzed in this paper.

For estimating the number of fruits for yield prediction, first pre-processing algorithms are applied on the images. The pre-processing of input image can be performed using A Gaussian low pass filter to reduce noise as much as possible. Noise portend to unequal color intensity distribution in the original images that formed shades and shiny regions in the image. [3]

For recognition, RGB color values can be used to segment apple fruit from the background. The majority of apple fruits in an image could be segmented from the background at a threshold color difference of R-B. Through calculating and analyzing R, G, B color values for each class, a threshold for the color difference G-R between apples and a falsely classified background is detected. [5]

Segmentation of a fruit image can be done using L*a*b color space, which is one of the two devices independent color spaces introduced by the Commission International del'Eclairage (CIE), for color segmentation. L*a*b space is designed in a way such that the colors which are visually similar are adjacent to each other in the color space .Because of its advantages it is used for color image segmentation.[3]

The k-Nearest Neighbors algorithm is the methodology that has been used to develop the Fruit Recognition System. The Fruit Recognition System uses the KNN algorithm as a classifier to classify fruit based on mean color values, shape roundness value, area and perimeter values of the fruit.[8] Circle fitting is an algorithm to fit a circle into scattered pixel data. Firstly the co-ordinates of the edge pixels were found. Then the mean of pixels is calculated. Then the center of the clusters using the mean is computed. For the segmented image color, shape, texture features are extracted. The extracted features are trained by fuzzy classifier and Fuzzy Logic has emerged as a profitable tool for the controlling and steering of systems and complex industrial processes, as well as for household and entertainment electronics, as well as for other expert systems and applications like the classification of SAR data.[2]

To study the state of art the related work in the field and problem are outlined.

Ulzii-Orshikh Dorj, Malrey Lee, and Sangsub Han[1] have adapted a new counting algorithm for tangerine yield estimation to obtain better results with respect to partially / semi partially occluded tangerine and its clusters. Under natural lighting conditions prediction of the tangerine fruits from the orchards is computed and compared between before harvesting, after harvesting tangerine fruits, and results of yield estimation through tangerine flower recognition which is closer to 20% of yield estimation result. The information of the tangerine grove was not properly estimated which resulted in poor implementation and low practical usability. for automation harvesting or inspection tests for identifying fruits / vegetables cluster on plants. Processing time was high.

Prof. Suvarna Nandyal, Jagadeesha [2] presented a Crop Growth Prediction Based on Fruit Recognition Using Machine Vision. In which the fruit region is located and segmented using edge detection and circular fitting algorithm. Morphological operations are adapted for segmented regions to get proper boundaries .The colour and shape features are extracted for the fruit region. The recognition accuracy of only 90% is observed. Segmentation and feature extraction were not up to the mark.

H N Patel, A D.Patel [3] have worked on efficient locating the fruit on the tree is one of the major requirements for the fruit harvesting system. Color and shape analysis was utilized to segment the images of different fruits are obtained under different lighting conditions. The pre-processing of the input image was performed first, Segmentation of a fruit image, Binary noise-removed image was labelled to extract the fruits, Fit the Circle to the edge points. The results indicate that the proposed method can accurately segment the occluded fruits with the efficiency of 98%. The average yield measurement error was found as 31.4 %.Algorithm could not be used for automatic crop health management.

Raphael Linker, Oded Cohen, Amos Naor [4] has worked on determining the number of green apples in RGB images recorded in orchards. The algorithm includes four main steps: detection of pixels that have a high probability of belonging to apples, using colour and smoothness; formation and extension of ''seed areas'', which are connected sets of pixels that have a high probability of belonging to apples; segmentation of the contours of these seed areas into arcs and amorphous segments; and combination of these arcs and comparison of the resulting circle with a simple model of an apple. It faced difficulties such as natural light is not diffusive enough and might cause strong shading and saturation, and apples have variable sizes and colour, overlap other objects, and are rarely fully visible which if worsened then the errors could be unacceptably high.

Rong Zhou, Lutz Damerow, Michael M. Blanke [5] has implemented Recognition Algorithms for Detection of Apple Fruit in An Orchard for Early Yield Prediction. An apple recognition algorithm with colour difference R-B and G-R was developed for apple images after June drop, and two different colour models were used to segment the ripening period's apple images. The algorithm was tested on 50 images. A close correlation coefficient R2 of 0.80 was obtained between apples detected by the fruit counting algorithm and those manually counted. Site-specific management was not properly implemented as yield prediction information was not available.

H N Patel, A D.Patel [6] has worked on efficient locating the fruit on the tree which is one of the major requirements for the fruit harvesting system. This paper presents the fruit detection using improved multiple features based algorithm. To detect the fruit, an image processing algorithm is trained for efficient feature extraction. The algorithm is designed with the aim of calculating different weights for features like intensity, color, orientation and edge of the input test image. The Detection Efficiency is achieved up to 90% for different fruit image on tree, captured at different positions.

A.R. Jimenez, R. Ceres and J.L. Pons [7] have surveyed previous studies to automate the location of fruit on trees using computer vision methods. Three different types of images were used in the reviewed works: intensity, spectral or range images. It paid special attention to the sensors and accessories utilized for capturing tree images, the image processing strategy used to detect the fruit, and the results obtained in terms of the correct/false detection rates and the ability to detect fruit independent of its maturity stage. The approaches using range images and shape analysis were capable of detecting fruit of any colour, did not generate false alarms and gave precise information about the fruit three-dimensional position. The best results obtained indicate that more than 85% of visible fruits are usually detectable.

Woo Chaw Seng [8] presented a new Fruit recognition system has been proposed, which combines three features analysis methods: colour-based, shape based and size-based in order to increase accuracy of recognition. For Fruits Recognition System, the KNN algorithm performs fruit classification by using the distance measure system shows the fruit name and a short description to user. Proposed fruit recognition system analyzes, classifies and identifies fruits successfully up to 90% accuracy.

P. Wijethunga, S. Samarasinghe, D. Kulasiri1 I. Woodhead [9] has implemented a Digital Image Analysis Based Automated Kiwifruit Counting Technique. Three simple counting methods followed by a minimum distance classifier based segmentation technique in L*a*b colour space were studied. Above 90% accuracy on gold image data and above 60% accuracy on green image data were obtained, showing the potential of using the approach for counting kiwifruit for the harvest estimation purpose.

P. Annamalai, Won Suk Lee, Thomas F. Burks [10] have investigated machine vision system utilizing colour vision as a means to identify citrus fruits and to estimate yield information of the citrus grove in real-time. Images were taken in a stationary mode using a machine vision system. The threshold of segmentation of the images to recognize citrus fruits was estimated from the pixel distribution in the HIS colour plane. A computer vision algorithm to enhance and extract information from the images was developed. The results indicate that yield prediction model could be enhanced by using multiple cameras for covering the majority of tree canopy.

III. ANALYSIS AND DISCUSSION

The literature survey present in this paper shows that L*a*b color space transformation of RGB image provides better segmentation result with K-means clustering or color based nearest neighbor classifier. After the color based segmentation of image, circle fitting algorithms can be applied followed by morphological operations to separate all fruits on the tree. Then the counting of fruits can be done. In parallel the fruit recognition algorithm can be used by extracting various color and shape features of fruit.

An efficient fruit counting and yield mapping algorithm can be implemented by using fuzzy logic based classification for fruit recognition and counting. Further the new segmentation techniques should be adopted to count the number of green apples on trees.

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Detecting Tomato Flowers in Greenhouses Using Computer Vision. Authors: Dor Oppenheim, Yael Edan, Guy Shani.Â This paper presents an image analysis algorithm to detect and count yellow tomato flowers in a greenhouse with uneven illumination conditions, complex growth conditions and different flower sizes. The algorithm is designed to be employed on a drone that flies in greenhouses to accomplish several tasks such as pollination and yield estimation.Â [7] A. R. JimÃ©nez, R. Ceres, and J. L. Pons, â€œa Survey of Computer Vision Methods for Locating Fruit on Trees,â€ Trans. ASAE, vol. 43, no. 6, pp. 1911â€“1920, 2000. [8] D. R. Martin, C. C. Fowlkes, and J. Malik, â€œLearning to detect natural image boundaries using local brightness, color, and texture cues,â€ IEEE Trans. Recent years have witnessed significant advancement in computer vision research based on deep learning. Success of these tasks largely depends on the availability of a large amount of training samples. Labeling the training samples is an expensive process.Â Computer vision-based crop yield estimation methods can be divided roughly into two categories: (1) region- or area-based methods and, (2) counting-based methods. In the literature, there is an ample amount of work dealing with region-based methods [20,21,22,23,24,25,26].Â Finally, the last fully-connected layer after the dropout layer gives the prediction for the number of tomatoes in the input image. Batch normalization was performed after every convolution to remove the internal covariate shift [38].