Giuseppe Pellizzi Prize 2018

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Machine Vision System for Robotic Apple Harvesting in Fruiting Wall Orchards

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Extended Abstract

Mechanization in agriculture is often regarded as one of the greatest human achievements of the twentieth century. These technological advancements have led to significant reduction in human effort in the production of bulk agricultural commodities such as corn and wheat. Specialty crop industry such as fresh market fruit, on the other hand, are still dependent on manual labor for various production operations such as training, thinning, pruning, and harvesting. Among these, tree fruit harvesting of high value crops like apples are some of the most labor intensive and time sensitive tasks requiring high number of farm workers at right (and for short) time. To increase productivity and reduce dependency on seasonal labor, researchers have proposed several concepts of automated harvesting systems. Because of highly unstructured orchard environment and variable outdoor lighting conditions, these technologies have only achieved limited successes in the past. No commercial viability has been achieved and every apple destined for fresh market is still handpicked. The lack of mechanized harvesting system has the potential to threaten the long-term sustainability of fresh fruit industry in the United States and around the world.

This dissertation focuses on the study and evaluation of a machine vision system and an integrated robotic system for automated harvesting of apples grown in modern fruiting wall orchards. The machine vision algorithm designed to work in orchard environment accurately detected apples growing individually as well as in heavy clusters under variable natural lighting conditions. A pragmatic approach to harvesting (also called hierarchical approach) showed that 98% of the fruit could be detected in narrow fruiting orchards with iterative imaging and harvesting of most visible fruits. The integrated robotic system with a global camera and custom built seven degrees of freedom manipulator successfully picked 84% of attempted fruit with 6 seconds of average harvest time per fruit. This approach of selective apple harvesting with a global camera system and low-cost manipulator show a huge potential for cost-effective robotic solutions for harvesting fresh market apples. However, several limitations still remain to be addressed for commercialization.

1. Introduction

On average, 15-18 billions apples are produced in the state of Washington representing approximately 70% of apple market in the U.S; each of these apples destined for the fresh fruit market are handpicked. Amongst numerous tasks throughout the fruit production cycle, harvesting is the most labor intensive field operations that requires a large number of farm workers for generally a short and specific period of time. To reduce dependency on and cost of such seasonal labor force, research and development of robotic tree fruit harvesting systems have received a renewed focus in recent years

By nature, agricultural work spaces such as apple orchards are biologically driven environment. Some of the distinct characteristics of such environment include unstructured and complex canopy structures, varietal differences, fruit clusters and occlusion, inconsistency in fruit shape and size, variation in natural lighting, and delicate nature of commodities. These factors only increase the uncertainty in the repetitive task of harvesting fruits from the canopy. The scenario presented above is drastically different from industrial floors which are highly structured and well organized. Although numerous attempts and extensive resources have been devoted to transfer industrial robotics into agricultural field-based applications, no commercial success has been achieved in automated harvesting systems for fresh market fruit and vegetable crops

2. Literature Review

Robotic apple harvesting is an intricate and challenging problem that has eluded researchers for several years. The task of robotic harvesting of apples can be categorized primarily into two components; machine vision system for fruit detection and localization, and mechanical means to picking and transporting fruit into bins. This chapter presented a detailed review of relevant literatures in this area. All sub-steps within the two categories combined present a highly complex problem with several bottlenecks. For example, the performance of the vision system is often limited by variable outdoor lighting, occlusion, and fruit clustering whereas the mechanical system suffers from end-effector robustness, kinematic solutions, and limited reachability. A successful harvesting system design requires a proper balance between speed, cost, and robustness and sometimes these factors are contrary to each other.

3. Identification of Red Apples in Field Environment with Over the Row Machine Vision System

Accurate detection and identification of fruits is critically important for the success of developing automated apple harvesting system. Past research to identify apples in orchard environment have shown reasonable accuracy when apples are clearly visible or partially occluded. However, only limited work has been carried out to identify fruit in clusters, which is critically important as fruit clusters are common in field conditions. This work focused on accurately identifying partially visible apples and apples in clusters. An over the row platform with tunnel structure and artificial lighting was used to increase uniformity of light intensity in images. Iterative Circular Hough Transform was then used to detect clearly visible fruit as well as individual fruit in cluster. Partially occluded apples were detected using a clustering algorithm based on distance between centroids of blobs that were later merge as parts of an apple divided by occlusion. This algorithm was successfully tested on images acquired in field condition and resulted in 90% identification accuracy, false positive of 1.8%, and false negative of 8.2%. The multi tire approach significantly increased detection accuracy compared to individual methods exclusively including fruits in clusters. The results showed potential for in-field apple identification for automated apple harvesting.

4. A Hierarchical Approach of Apple Identification for Robotic Harvesting

The previous chapter showed a robust way to detect apples in commercial orchards. However, the vision system for robotic harvesting requires a strategy to better deal with fruit occlusion and clusters. This work presents a hierarchical method for apple identification suitable for robotic harvesting. The vision system described in the above section was applied iteratively on six overlapping sections of tree canopies trained in fruiting wall architecture. Clearly visible fruit identified by CHT were preferred to partially visible apples for initial harvesting. These prioritized apples were then manually picked to prove the concept of hierarchical fruit identification approach. As images were taken again after harvesting well–exposed apples, partially or fully occluded apples were better exposed in successive iterations. This iterative process was applied over every image acquired from both sides of tree canopies until no apples were identified. In total, 740 images were taken from 240 canopy sections of 20 trees where 1789 apples were identified out of 1827 manual counts. On average, this method achieved 98% of identification accuracy. Although this process is simple and intuitive, the work provided a unique and novel insight into the fruit identification and harvesting accuracy achievable with such an approach in field environment.

5. Design, Integration, and Field Evaluation of a Robotic Apple Harvester

Despite extensive research over the past four decades, there are no mechanical apple harvesters commercially available for fresh market tree fruit harvesting, which is a significant concern because of increasing uncertainty about the availability of manual labor and rising labor costs. The highly unstructured orchard environment has been a major challenge to the development of commercially viable robotic harvesting systems. This work reports the design and field evaluation of a robotic apple harvester. The approach adopted was to use a low–cost system to assess required sensing, planning, and manipulation functionality in a modern orchard system with a planar canopy. The system was tested in a commercial apple orchard in Washington State. Workspace modifications and performance criteria are thoroughly defined and reported to help evaluate the approach and guide future enhancements. The machine vision system was accurate and had an average localization time of 1.5 s per fruit. The seven degree of freedom harvesting system successfully picked 127 of the 150 fruit attempted for an overall success rate of 84% with an average picking time of 6.0 s per fruit. Future work will include integration of additional sensing and obstacle detection for improved system robustness.

6. Overall Conclusion

In this dissertation, innovative concepts were investigated to address some of the bottlenecks in both sensing and picking technologies, which were then integrated into the design and field evaluation of a prototype robotic apple harvester. The integrated system was able to detect fruits and manipulate the arm to pick fruits autonomously in a formally trained commercial orchard.

Final remarks concerning the competition benchmarks and strength points

[compulsory chapter to fill with 500 characters max, spaces included]