Computers and Electronics in Agriculture 116 (2015) 8–19

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Review

Sensors and systems for fruit detection and localization: A review

A. Gongal [a,b], S. Amatya [a,b], M. Karkee [a,b,*], Q. Zhang [b], K. Lewis [b,c]

[a] Biological Systems Engineering Department, Washington State University, United States
[b] Center for Precision and Automated Agricultural Systems, Washington State University, United States
[c] Extension, Washington State University, United States

ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form 30 May 2015
Accepted 30 May 2015
Available online 18 June 2015

Keywords:
Machine vision
Fruit detection
Fruit localization
Robotic harvesting
Crop-load estimation
Specialty crops

ABSTRACT

This paper reviews the research and development of machine vision systems for fruit detection and localization for robotic harvesting and/or crop-load estimation of specialty tree crops including apples, pears, and citrus. Variable lighting condition, occlusions, and clustering are some of the important issues needed to be addressed for accurate detection and localization of fruit in orchard environment. To address these issues, various techniques have been investigated using different types of sensors and their combinations as well as with different image processing techniques. This paper summarizes various techniques and their advantages and disadvantages in detecting fruit in plant or tree canopies. The paper also summarizes the sensors and systems developed and used by researchers to localize fruit as well as the potential and limitations of those systems. Finally, major challenges for the successful application of machine vision system for robotic fruit harvesting and crop-load estimation, and potential future directions for research and development are discussed.

Contents

* Corresponding author at: 24106 N Bunn Rd, Prosser, WA 99350, United States. Tel.: +1 509 786 9208.
E-mail address: manoj.karkee@wsu.edu (M. Karkee).

http://dx.doi.org/10.1016/j.compag.2015.05.021
0168-1699/

1. Introduction

Harvesting of specialty crops such as apples, citrus, cherries and pears is highly labor intensive and is becoming less sustainable with increasing cost and decreasing availability of a skilled labor force. In Washington State alone, more than 15 billion apples have to be handpicked by seasonal labor with an estimated harvesting cost of $1150–$1700 per acre per year (Gallardo et al., 2010). Further, hand harvest activities pose high risk of back strain and musculoskeletal problems to fruit pickers due to repetitive hand motions, awkward postures while picking fruit at high locations, and ascending, and descending on ladders with heavy loads (Fathallah, 2010). Hofmann et al. (2006) found that $21 million compensation was paid for ladder-related injuries in the Washington State tree fruit industry between 1996 and 2001, which accounted for almost half of all compensable claims in that sector for the six-year period. Projecting into the future, the labor issue is expected to become more critical in terms of both increasing costs and uncertain availability (Fennimore and Doohan, 2008). Thus, automated or robotic harvesting system is essential to meet the increasing labor demand, to lower human risk of injuries in orchards, and to decrease the harvesting cost by saving time, money, and energy, which is profitable to both producers and consumers.

Schertz and Brown (1968) first proposed the concept of automated harvesting as an alternate to mechanical harvesting. Sistler (1987) argued that research and development on machine vision, robotics, and intelligent machine is key to improve the sustainability of specialty crop production in USA. Pejsa and Orrock (1984) and Sistler (1987) indicated that citrus fruit and apple has greatest potential for fruit detection and robotic harvesting. However, there have been several challenges in the successful development of such technologies; (i) lack of a clear direction for agricultural automation and robotics among researchers, commodity groups, and governments; (ii) variable and uncertain outdoor environment; (iii) complex plant structure; (iv) variable product shape and size; and (v) lack of support system for repair and maintenance of equipment (Sistler, 1987). Although no robotic or automated system has yet been commercialized for harvesting fresh-market tree fruit crops, various researchers, and private companies, have attempted fruit detection, localization, and robotic harvesting from different perspectives. Li et al. (2011) recognized that substantial improvement in fruit detection and localization accuracies is necessary to practice robotic harvesting. Detection and localization of fruit are the most fundamental information for machine vision based harvester. Efforts in improving fruit detection and localization will also help to improve accuracy of crop-load estimation.

Numerous research efforts have been reported in the literature on the development of a machine vision system for image acquisition, fruit detection, and fruit localization for robotic harvesting of fruits (Parish and Goksel, 1977; Harrell et al., 1985; Yang et al., 2007; Baeten et al., 2008; Scarfe et al., 2009; Bulanon et al., 2010; Yamamoto et al., 2014). However, proper synthesization of the literature to provide a clear guidance on the state-of-the-art and potential future direction has been lacking. Thus, this review paper is focused on providing up-to-date information on studies carried out so far in the area of fruit detection and localization in specialty crops for robotic harvesting and/or crop-load estimation.

2. Sensors and systems for fruit detection

Accuracy of machine vision systems in the detection and localization of fruit is affected by uncertain and variable lighting conditions in the field environment, variable, and complex canopy

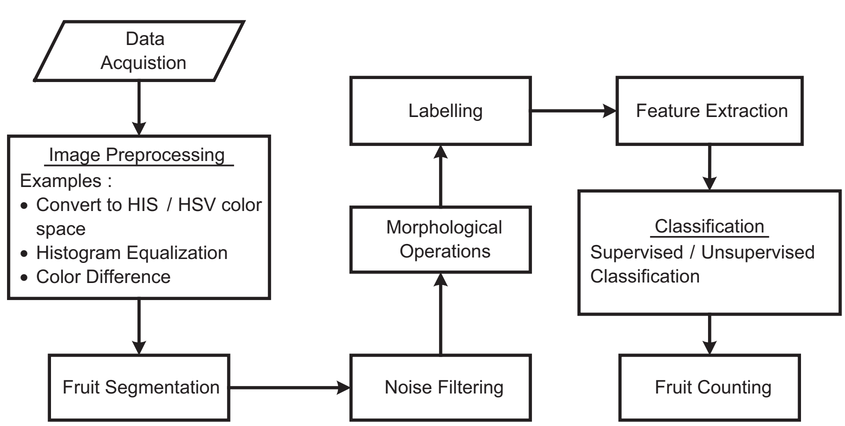

Fig. 1. Block diagram of steps involved in fruit detection.