Computers and Electronics in Agriculture 128 (2016) 127–140

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

3D pose estimation of green pepper fruit for automated harvesting

Peteris Eizentals *, Koichi Oka

Department of Intelligent Mechanical Systems Engineering, Kochi University of Technology, Tosayamada, Kami-city, Kochi 782-8502, Japan

ARTICLE INFO

Article history:
Received 4 January 2016
Received in revised form 23 August 2016
Accepted 29 August 2016
Available online 3 September 2016

Keywords:
Pose estimation
Automatic harvesting
Harvesting robot
Green pepper
Point matching

ABSTRACT

This paper presents a novel pose estimation algorithm for stem position detection in Japanese green pepper automatic harvesting. When the available visual cues do not provide sufficient information to the harvesting robot, information about the pose of the fruit in space is necessary for accurate stem position detection. In the proposed method the orientation of a fruit in space is obtained by fitting a model to surface points of the fruit. These surface points are acquired using a Lidar type laser range finder, and the point matching is performed using a coherent point drift algorithm with two model transformation methods, rigid and affine. The performance of the proposed method was evaluated both under laboratory conditions and in a greenhouse. In the laboratory test, the mean total error for the affine transformation was less than 25 mm in 42 of 49 positions, less than 20 mm in 28 of 49 positions and less than 15 mm in 19 of 49 positions. For the rigid transformation, the same error was less than 25 mm in 39 of 49 positions, less than 20 mm in 31 of 49 positions and less than 15 mm in 11 of 49 positions. The total error of the affine transformation was found to be proportional to the inclination angle, as the mean error was 11 mm, 15 mm, and 23 mm for inclination angles of 15, 30 and 45 degrees, respectively. No relationship was found between the mean total error and the inclination angle for the rigid transformation, as the calculated mean total error was 20 mm, 18 mm, and 20 mm for inclination angles of 15, 30 and 45 degrees, respectively. In the greenhouse test, the stem was calculated to be within the cutting range for 81 of 107 instances for affine transformation and for 66 of 107 for rigid transformation. These results suggest that the proposed method is suitable for stem position detection in the automatic harvesting of green pepper, and could be adjusted for use with other fruits and vegetables.

1. Introduction

Automatic harvesting consists of three sub-tasks, target detection, secure target grasping and detachment of the target from the plant. A substantial error in any of these tasks results in either an unsuccessful harvesting attempt or damaged plant. Low harvesting success rate together with low speed compared to that of a human worker are the main reasons for reluctance to adopt automatic harvesting robots in the field. For a harvesting robot to be competitive, the performance of the three sub-tasks must be improved in existing automatic harvesting robots. Successful grasping and detachment of a fruit depend on the information obtained in the target recognition step. Target recognition is a machine vision task, the execution of which depends on the fruit being harvested and the operating environment. The methods in common use currently range from simple RGB or HSI color space thresholding for easy-to-detect fruits such as strawberries (Qingchun et al., 2012), tomatoes (Kondo et al., 2009) and most citrus fruits (Hannan et al., 2007), to spectral imaging for fruits such as cucumbers (Van Henten et al., 2002) and green citrus fruits (Okamoto and Lee, 2009), which are more difficult to distinguish from the surroundings. A complete review of the machine vision methods currently used in automatic harvesting was done by Kapach et al. (2012). That paper also pointed to the necessity of 3D pose estimation to provide sufficient information for successful grasping and cutting. The necessity of pose estimation of the target fruit was observed by the authors of this paper in an ongoing study with the aim to develop an automatic harvesting robot for Japanese green pepper, locally known as *pīman* (ピーマン). Japanese green pepper is generally smaller than a bell pepper but has the same thick stem, which is one of the main reasons for frequently observed the slantwise growth of the fruits (Fig. 1). When only stereo imaging information is used, slantwise growth is an obstacle to accurate detection of the green pepper stem for cutting, especially when occlusions are present.

Knowledge of object pose in space is critical for a proper manipulation by robots in pick-and-place operations. This is especially true for automatic harvesting robots that require accurate

* Corresponding author.
E-mail addresses: peteris.eizentals@gmail.com (P. Eizentals), oka.koichi@kochi-tech.ac.jp (K. Oka).

http://dx.doi.org/10.1016/j.compag.2016.08.024
0168-1699/

Fig. 1. Japanese green pepper, the slantwise growth of the fruits is common and complicates automatic harvesting.

information about the location of a fruit and the stem of the fruit for cutting operation (Blanes et al., 2011). Previous general machine vision research has been done on the estimation of the 3D pose of free form objects (Rosenhahn and Sommer, 2004) and objects with the shape known *a priori* (Dambreville et al., 2008). Only recently has this problem attracted research attention in the context of agriculture. The typical approach to the pose estimation is based on matching a known predefined 3D model on the point cloud that represents the target object. This approach is relatively simple for quasi-spherical fruits such as tomatoes (Yasukawa et al., 2015), but a great variation in shape between fruits complicates providing a good general model for such fruits as peppers. To address this issues in the context of sweet pepper (capsicum) automatic harvesting, Lehnert et al. (2016) proposed a method that estimates the pose by the nonlinear least squares fitting of a box-shaped super-ellipsoid to the surface points of a target fruit. This method, however, is ill-suited for dealing with fruits that have much different shape than that of the model. Japanese green peppers, for instance, tend to have great shape variation and it is often different from that of a bell pepper. The necessity for a more appropriate parametric model is also pointed out by Lehnert et al.

This paper introduces a new method for Japanese green pepper 3D pose estimation for automatic harvesting. In this method, the pose of the green pepper fruit is calculated using a model matching algorithm, which finds the best fitting position for a model on the surface points of the target fruit. The surface points are obtained by Lidar type laser range finder and the model matching is performed using a coherent point drift (CPD) algorithm developed by Myronenko and Song (2010). A full working algorithm of the method presented here is given below along with the performance test results. The performance of the method was evaluated in laboratory conditions on test fruits with a known inclination angle and in a greenhouse on naturally growing fruits. The results of tests performed both under laboratory conditions and in a field study in a greenhouse support the applicability of the proposed method in automated harvesting of green pepper in a greenhouse environment.

2. Materials and methods

2.1. System overview

The proposed pose estimation algorithm was originally intended for a green pepper automatic harvesting robot, initially developed by Kitamura and Oka (2005) and later improved by Bachche and Oka (2013) (Fig. 2). The cutter used by this robot is a scissor–pincer system with a maximum opening width of 30 mm, and both cutting and grabbing tasks are performed by a single movement (Fig. 2c). The thickness of the green pepper stem is used to securely grasp the fruit by the stem after it is cut. The information about an accurate position of the stem is crucial for a successful harvesting using this method, but in many cases obtaining this information from only visual cues is very complicated. Occlusions, similarity to the rest of the foliage and the inclination of the fruit are the main reasons complicating an accurate detection of the stem position. Information on the size and the pose of a fruit in space is necessary to calculate a stem position when the stem can't be detected using the visual information. Lidar type laser range finder URG-04LX (Hokuyo Automatic Co. Ltd.) was

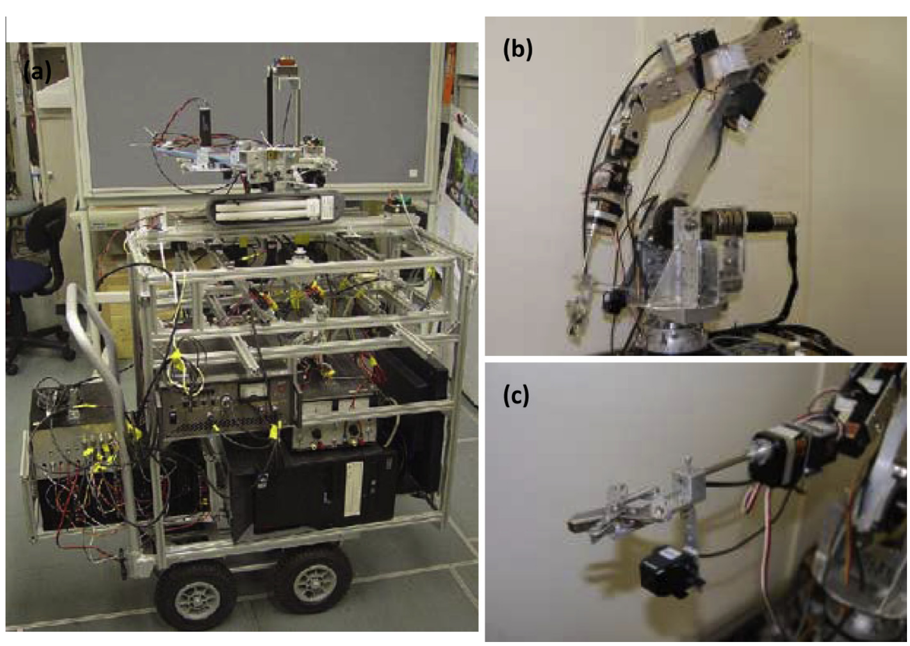

Fig. 2. The first prototype of the green pepper harvesting robot, (a) initial design and later improvements, (b) manipulator and (c) cutter.