Robotics and Autonomous Systems 59 (2011) 265–273

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

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

Plant detection and mapping for agricultural robots using a 3D LIDAR sensor

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ARTICLE INFO

Article history:
Available online 11 March 2011

Keywords:
Individual plant detection
Plant mapping
3D LIDAR sensor
Agricultural robotics

ABSTRACT

In this article, we discuss the advantages of MEMS based 3D LIDAR sensors over traditional approaches like vision or stereo vision in the domain of agricultural robotics and compare these kinds of sensors with typical 3D sensors used on mobile robots. Further, we present an application for such sensors. This application deals with the detection and segmentation of plants and ground, which is one important prerequisite to perform localization, mapping and navigation for autonomous agricultural robots. We show the discrimination of ground and plants as well as the mapping of the plants. Experiments conducted using the FX6 LIDAR by Nippon Signal were carried out in the simulation environment Gazebo, with artificial maize plants in the laboratory and on a small maize field. Our results show that the tested plants can be reliably detected and segmented from ground, despite the use of the low resolution FX6 sensor. Further, the plants can be localized with high accuracy.

1. Introduction

Precision agriculture is about applying the right treatment, at the right place and at the right time [1]. To be really precise the treatment should be carried out adapted for each crop plant. But, what is the right treatment, when and where should it be carried out? For making such decisions it is necessary to collect, store and process crop field data at a subfield level. Nowadays it is a common procedure to perform this task by human labor using random samples.

The labor-intensive nature of precision agriculture practices brings a great need for automation [2]. Hence, one main objective of precision farming is the automation of the rating, storage, management and decision making processes by using autonomous vehicles. In future, such vehicles are needed for soil sampling, crop scouting, and real-time data collection [2]. Because of the huge size and heavy weight of conventional field machinery and the resulting compacting of the field, small robots are preferable. Furthermore, small robots are better suited for individual plant care, such as selective crop harvesting and individual crop rating as well as precise spraying, fertilization and weeding, to reduce costs, fertilizers and pesticides.

The work presented here is a part of the publicly funded project BoniRob [3], a cooperation of academic and industrial partners, with the goal to develop an autonomous mobile agricultural robot. The key objective of BoniRob is the autonomous repeating phenotyping of individual plants at different days, for that it is necessary to detect and map single plants. The automatic phenotyping and mapping of all plants in a field will be a revolutionary change in the methods of field trials. Moreover, the availability of a robust crop scout will offer options for other field applications, such as stated in the previous paragraph.

A basic component of the crop scout is the navigation module, based on GPS localization and 3D environment sensing. The task of the navigation module is to guide the robot safely and autonomously over the field as well as to localize it even in unknown environments. For that purpose, in mobile robotics it is necessary to be sure about the position and the surroundings of the vehicle. In our case, we are detecting crop rows or even individual plants. We detect the individual plants because of different reasons: first for the navigation—the robot must follow a crop row without harming the plants, second for the localization—the rows and the plants can be used as natural landmarks and third for the mapping of the plants—we have to retrieve the individual plants because the phenotyping should be performed at different days to track the growth stages. Fig. 1 shows our test robot sensing the crop with a 3D laser sensor and a point cloud of an artificial crop row, also showing the detected plants.

At present, 2D vision based approaches are common for environment sensing in agricultural robotics. Some groups are using stereo vision to receive 3D data, but 3D laser sensors are not in the focus of the community. But, one obvious advantage of 3D laser sensors over 2D vision and stereo vision is the availability of reliable ranging data, which relieves the object detection and the object localization. Other advantages over 2D vision and other 3D sensor technologies are the robustness against illumination and atmospheric conditions, which enables the robot to operate reliable at any weather conditions even 24 h a day.

In the first part of this paper, we discuss the state-of-the-art in environment sensing in agricultural robotics and introduce the

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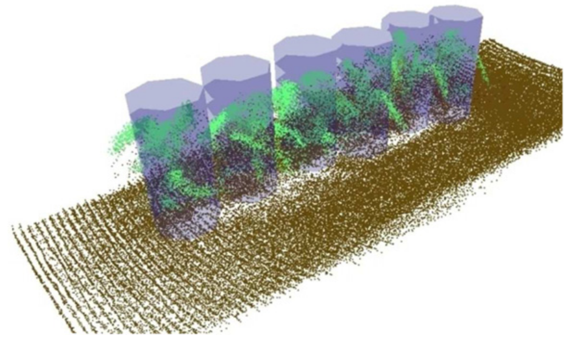
doi:10.1016/j.robot.2011.02.011

(a) Robot sensing maize plants.



(b) Point cloud and detected maize plants.

Fig. 1. In the picture (a) one can see our test robot on a maize field sensing the plants with the FX6 3D LIDAR sensor. The image (b) shows a point cloud of an artificial maize row, constructed using several laser scans. The points detected as ground are colored in brown; the points belonging to the plants are colored in green; the detected maize plants are marked using purple cylinders. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Micro-Electro-Mechanical Systems (MEMS) mirror based FX6 3D light detection and ranging (LIDAR) sensor by Nippon Signal [4]. We also compare this sensor with other state-of-the-art 3D sensor technologies suitable for mobile robotics. The second part of this paper is focused on an algorithm performing individual plant detection and mapping using a 3D LIDAR sensor on a mobile robot. Our proposed algorithm is based on an approach detecting the ground to segment the point cloud into soil and other objects. In the remaining point cloud it searches for clusters representing plants using a model of a crop row. According to the detected ground plane the plant localization and mapping is performed. In this paper we show that this task can be reliably carried out using the 3D-LIDAR sensor with its resolution of 59×29 rays. According to [5] the required localization accuracy for the task of individual plant treatment is about 1 cm. To achieve almost this precision we are applying sensor fusion for the global positioning of the robot using a real-time-kinematic (RTK)-GPS device, the odometer and an inertial measurement unit (IMU). The accuracy of this sensor fusion is about 2 cm, which has shown in our experiments to be sufficiently precise for our task.

This paper is organized as follows. In Section 2 we discuss the state-of-the-art of environment sensing in the domain of agricultural robotics and compare typical 3D sensors used on mobile robots with the FX6 sensor. The algorithm performing the ground and plant detection as well as the mapping is introduced in Section 3. Section 4 shows the experimental results. Finally, in Section 5, the conclusions and the future works are presented.

2. Environment sensing in agricultural robotics

2.1. State-of-the-art

If one is to believe [6], the most promising system of relative positioning is computer vision using cameras. Indeed, at present, for environment sensing in agricultural robotics and for automatic guidance in crop rows most approaches recently traced are 2D vision based. The main challenge here is to interpret the images to find a guidance directrix, e.g., the position and orientation of the crop rows relative to the vehicle [2].

There are many publications dealing with this topic, e.g. in [7] the authors present a vision based method for crop row recognition using the Hough Transform which is also robust against the presence of weed. By using a near-infrared filter on a gray-scale camera they get a high contrast image where living plant material and soil is easily discriminated. Tellaeche et al. [8] combine Support Vector Machines and k-means Fuzzy Logic for detecting weed in cereal crop cultivations at early growing stages. They partition the image into cells, each described by two area-based attributes measuring the relation between crop and weed. John Billingsley introduced in [9] an overview over agricultural applications for 2D machine vision by several researchers, for task such as weed detection and eradication, automatic vehicle guidance, visual grading of produce, and identification and segregation of animal species.

Stereo vision systems are also known in agricultural applications, like [10] introduce two techniques for corn plant and population sensing, namely an active and a passive approach. In [11] stereo vision is used for the mapping of an agricultural environment like apple trees. Another application using stereo vision in this domain, proposed in [12], is obstacle detection to enhance safety by detecting persons in front of the vehicle.

One big disadvantage using vision or stereo vision is the influence by changing lighting conditions, which are not uncommon in outdoor applications like agriculture [2]. Laser rangefinder are a much more reliable technology in such situations, but up to now applications with laser sensors are rare in this domain. E.g., Satow et al. [13] developed an automatic crop row guidance system for tractor mounted implements, with a 2D line laser able to detect the height and the position of crop rows. Applications using 3D LIDAR sensors are not known in this domain.

The above mentioned publications deal with crop row detection to guide vehicles or with crop/weed/soil-discrimination but not with single plant detection and mapping. In [14] an approach for detecting individual plants, by generating an image using a light curtain which is moved along a crop row, was presented. Using a RTK-GPS on a non-autonomous mobile unit and sensor fusion they are able to generate a map of the crop rows with the position of individual plants. With such a sensor single plants can be detected, but the image generation depends on accurate position data, and because of the line characteristic of the sensor an image of a plant is not available until the vehicle pasts the object completely with the curtain. Another disadvantage is the necessity that the curtain has to be mounted at a low level to sense a whole plant, but at this level it may touch the plants. This sensor is also not able to look forward, which is required for the navigation task. In contrast, the method presented in this paper is able to detect individual plants up to a distance of 3 m in front of the robot, depending on the sensor mounting position.

2.2. 3D sensors in mobile robotics

Until today, most mobile robot implementations in indoor environments rely on 2D sensors for building maps, self-localization and collision avoidance. This is justified to some extent