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Prototype design guidelines for robotized targeted fertilisation in strip-cropping systems

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Abstract: Abstract

Organic agriculture has an increasing demand, driving conventional farmers to change their businesses [1]. In some cases, the lack of attention for biodiversity and soil fertility of current practices may damage the credibility of organic products [2]. The SUREVEG project focuses on the implementation of strip-cropping in organic production to improve soil fertility and biodiversity throughout Europe. The aim is to enhance resilience, system sustainability, local nutrient recycling, and soil carbon storage [3]. However, husbandry crops grown and mixed in a strip design pose new challenges regarding mechanisation, which in many cases can only be overcome by increasing human tasks [4]. To counteract the additional labour of a multi-crop system, one of the main objectives of this project is the development of automated machinery for the management of strip-cropping systems. A robotic tool is proposed, which will be operating upside down, attached to a wide-span mobile carriage similar to gantry systems used in Controlled Traffic Farming. Within the project framework, a modular proof-of-concept version is being produced, combining sensing technologies with actuation in the form of a robotic arm. Despite many robotic developments recently presented, which are designed for weed removal, this proof-of-concept will focus on providing precise organic fertilization. Fertiliser needs will be identified in real-time and carried out on a single-plant scale. Design guidelines of the proposed prototype have been detailed. The planning and control of the manipulator are being developed in two ways: using conventional algorithms and applying machine learning techniques. First results have been also obtained with the sensorics onboard the robotic platform, by using a combination of LiDAR systems and multispectral cameras to localize single plants, and to detect their status, according to fertilisation demands.

Introduction

Research with a multifocal approach is needed in order to solve organic farmers' challenges [5]. The SUREVEG project proposes the development and application of new organic cropping systems using strip-cropping and applying alternative fertility strategies to improve resilience, system sustainability, local nutrient recycling and soil carbon storage. The WP4 of the SUREVEG project is focused on creating smart machinery [6]. This WP aims at developing a robotic tool for the automation of field operations in strip-cropping systems, including the adequate sensors to collect crop data and actuators to apply precise organic fertilization.

The novelty of this work relies on the use of automation and robotics to apply tailored organic fertilisation at single plant scale. Currently several companies have announced robotic tools for scouting (data gathering) the fields or removing weeds mechanically, but no commercial development has been made towards organic fertilisation of crops, which can help organic growers.

Material and methods

Along the design phase of the robotic tool, several requirements were established for its development in different areas, concerning global requirements (work over rows of mixed cops), acquisition of information (sensorics), actuation (fertilisation at single-plant level), decision making, communication and validation. In order to meet these requirements, the system design is made up of a wheeled chassis, a manipulator robot, a tank with spraying system, sensors and cameras.

In parallel with the construction of the prototype, different experiments are being carried out to test the sensor systems. Specifically, 3 laser scanners (SICK LMS-111) are used simultaneously over strip of cabbages [7], tomatoes and pumpkins. A specific algorithm has been developed and applied on the resulting 3D point cloud in order to identify and reconstruct single plants. Also, a multispectral camera (Parrot Sequoia) was used to capture VIS-NIR images on tomato plants with different liquid organic fertilization treatments (T0 to T3), in order to obtain indexes related to crop nutrient demands.

Results

A robot with 5 degrees of freedom (DoF) like the one shown in Figure 1 has been chosen for this application. When the robot is located over the target plant, the first DoF (q1) allows to rotate around the plant, the next three DoF (q2, q3 and q4) allow to define the location of the tool and orientate it to the plant, and the last DoF (q5) allows to rotate the tool around its normal axis. As a result, the manipulator can take pictures of whole plants and apply treatments to the ground around them.

According to the design, the robot will have a reach of 790 millimeters and a precision of 1 millimeter. Additionally, it will weight around 20 kg , including the electromechanical components and excluding the control and power elements, and have a load capacity of around 2,5 kg.

An operator interface will be developed to monitor and control the system work . This interface will allow the operator to start/stop the system, send pose goals to the robot and activate/deactivate the actuator. The interface will provide the operator with information about the state of the cart and robot. Additionally, it will show the 3D model of the crop row and the multispectral images of the plants.

A set of algorithms are being developed to plan the trajectories of the robot towards the pose goals, process the data collected by the laser scanner and the multispectral camera and discover the information about the state of the plants and the recommended actions.

The research on the planning and control of the manipulator is being developed in two ways: using conventional algorithms and applying machine learning techniques. The objective is to generate trajectories for this robot that suround the plants without colliding with them. In this manner, the robot will be able to apply liquid treatments on the ground without damaging the plants.

On the one hand, the manipulator robot has been integrated in Robot Operating System (ROS), plus the MoveIt Motion Planning Framework. Conventional planning are being used to generate trajectories. However, there are some challenges to tackle, due to the robot has less than 6 degrees of freedom and the restrictions for its trajectories are important.

On the other hand, machine learning techniques could help to overcome these challenges. In this case, reinforcement learning is being applied with a simulator. This technique trains a neural network by defining its inputs (observations, such as the robot pose and next goals), outputs (actions, such as the movements of the robot joints) and rewards (positive or negative outcomes assigned to the robot when its movements are good or bad to reach its goals, respectively). An optimization algorithm adjusts the parameters of the neural network to maximize the reward obtained by performing the tasks.

Regarding the sensorics, current results on the recognition of plants using LiDAR sensors show that it is feasible to differentiate plant from ground by applying different segmentation criteria to the three-dimensional cloud [7], in order to segregate each single cabbage. Results on the application of multispectral cameras are shown in Figure 2, where images from a series of tomato plant replicates are depicted, along 36 days of treatment with 4 rates of liquid organic fertilization. First results indicate that, in most cases, image recognition techniques are better related to plant nutrient status than general vegetation indexes.

Discussion

A multidisciplinary work is currently being carried out to develop a robotic tool for autonomous organic fertilization at single plant level. First results indicate that it is possible to move a robotic platform with sensorics and an actuation system over a strip-crop field, acquire information of the location and morphology of the plants, along with data about their nutrient status, for tailoring crop precision fertilization.

Figure 2: Prototyped robotic platform with arm and sensorics

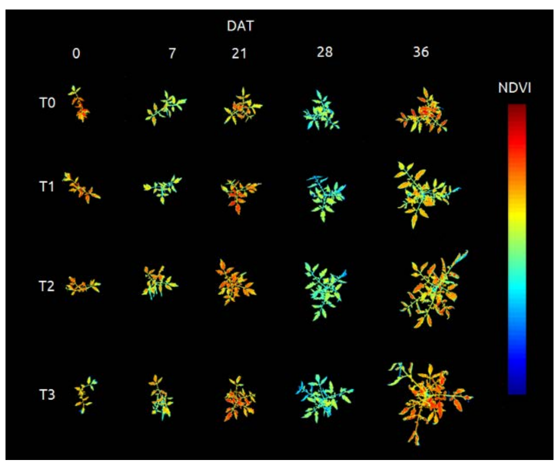

Figure 1. Multispectral images of tomato plants treated with organic fertilisers

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