POLITECNICO DI TORINO

MASTER'S DEGREE IN MECHATRONIC ENGINEERING

Navigation Algorithms for Unmanned Ground Vehicles in Precision Agriculture Applications

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Abstract. With the rapid growth of the world population over the past years the agriculture industry is asked to respond properly to the exponential augmentation of global demand for food production. To do so, it is easy to infer that the agriculture output must be increased rapidly. However, due to environmental resources limitations, this task is not straightforward, therefore, new techniques aimed to maximize the efficiency of every single land in a sustainable way are required. To this purpose, as days pass, more and more researchers are focusing their attention on the development of innovative smart farming and precision agriculture technologies by introducing automation and robotics into the agricultural processes.
This thesis is aimed to provide a low cost solution for an autonomous navigation in an unknown outdoor environment using only a camera sensor. More specifically, it presents two algorithms able to successfully carry out an autonomous navigation in vineyards adopting machine learning and computer vision techniques. Such algorithms have been developed for applications in vineyards but they can also be employed in orchards and in any other analogous scenarios.
The work proposed in this thesis proved to be very reliable when performing motion planning by elaborating the images acquired by the camera. Nonetheless, it is to be considered as a starting point for further research in this sector.

1. Introduction

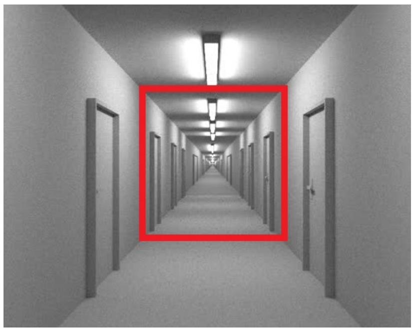
After the mechanization and the genetic modification, precision agriculture is also known as the third revolution in the history of agriculture. It refers to the utilization of automation and robotics on agricultural processes and its main goals are to reduce the high labor costs and to improve the production efficiency minimizing the impact on the environment.
Robotics and automation have a wide range of application in agriculture and it can be subdivided in three main categories:

- The use of sensors to control with very high precision when and where to apply inputs such as fertilizers and water in order to maximize the production efficiency
- Field crop machinery provided with an auto-pilot system
- Machines that harvest fruits and vegetables for processing

The objective of this thesis is to provide an algorithm for unmanned ground vehicles that performs an autonomous navigation in an agricultural scenario such as a vineyard using only a camera sensor (i.e. images). In particular two different approaches adopting computer vision and machine learning techniques, respectively, have been implemented. They have been designed to have a low computational complexity and memory utilization in such a way that they do not need a particularly heavy hardware to be executed.

2. Computer Vision Approach

This approach relies on the stereo geometry properties of the stereo camera and methods for edge detection. Imagine to walk along a corridor, the goal is to arrive at the end of the corridor, to do so, at every step, you must go towards the center of the largest window that groups all the points beyond a certain distance as shown in the figure to the right. It can be noticed that all the content of the red rectangle consists in a set of points with the common property to be farther than a certain distance with respect to the observing point.



Therefore, the objective of this algorithm is to detect that window in a vineyard row and then to compute the control commands in order to make the vehicle move towards its center. To find the window several steps are required. The first one is the acquisition of the image by the stereo camera and the computation of the depth map from the acquired frame. Then, the algorithm normalizes the depth matrix (depth map) and it applies a threshold on each entry of the matrix. Now, the processed frame is a black and white image (matrix with only zeros and ones) that is characterized by some white areas that define the far field (the candidate goals) and a black area that defines the near field. On this image an edge detection procedure is applied in order to delimit the white areas with rectangles. After that, another threshold on the size of the largest rectangle is employed to filter out the false positives. The remaining rectangle is the final window used for the control of the robot. The controller computes angular and linear velocities proportionally to the horizontal distance (in pixels) between the center of the camera frame and the center of the detected window.

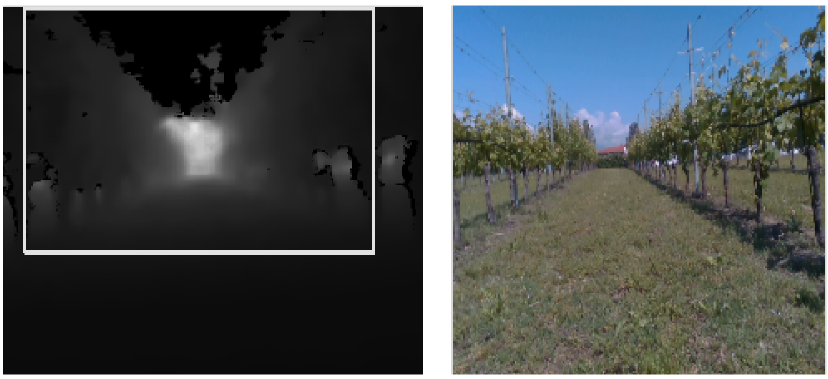


Figure 1. Example of window detection in a vineyard row

3. Machine Learning Approach

The idea behind this approach is to use a machine learning model in order to classify the view of the camera into one of the following three classes: left, center and right. Where, in a vineyards scenario, the class center describes the view of the camera when the robot is pointing at the end of the vineyard row, whereas, the classes left and right, are needed to indicate whether the robot is pointing at the left side or at the right side of the vineyard row respectively.
Further details and experimental results regarding this part of the thesis are omitted due to it being currently under patenting procedure.

4. Navigation Results and Conclusions

As far as the machine learning approach is concerned the good performances can be considered as a good starting point for additional research on using deep learning as a tool for the autonomous navigation in precision agriculture. In fact, this approach has been developed specifically for applications in vineyards, where it has also been tested, but it can also be employed in orchards and in any similar scenario by using a different dataset to train the machine learning model.
The second solution proposed in this thesis is a valid alternative, however, it presents some weaknesses when dealing with particular scenarios in which the vegetation is not particularly well maintained. Nonetheless, the algorithms proposed in this thesis do not achieve a complete navigation in the whole vineyard field but just along the rows. Therefore, further research activity must be carried out focusing on the recognition of the end of the row and the motion planning when it is required to move from a row to the next one.

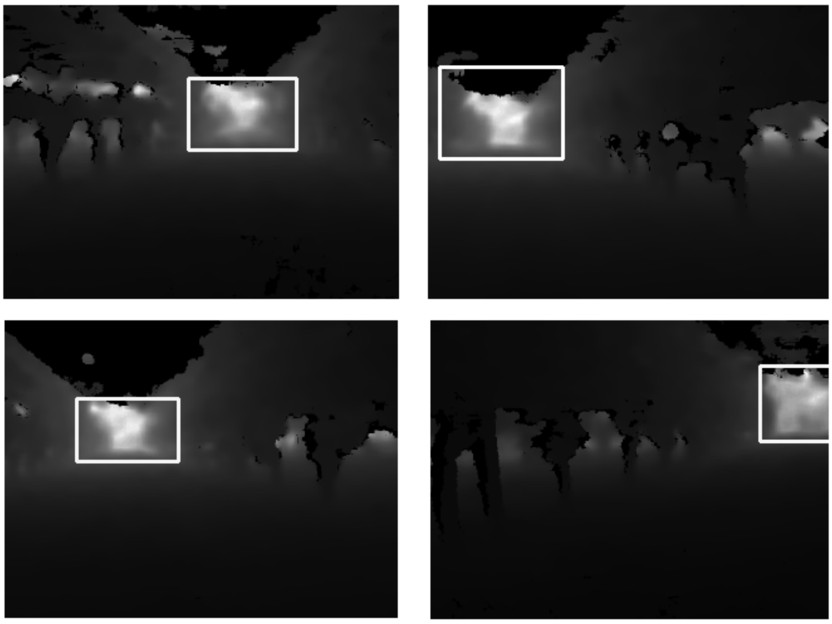


Figure 2. Experimental results of the computer vision approach