Autonomous Tracked Agricultural UGV Configuration and Navigation Experimental Results

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Abstract— **Nowadays agricultural techniques are increasingly focusing onto self-driving machines and smart robotic tools designed to support the farmer.**
This paper frames within this context, describing hardware and software configuration of the developed experimental robotic platform and reporting the results of practical tests about autonomous navigation within orchards.
The robotic system consists in a completely-electrical trucked vehicle equipped with GPS receiver, 3D laser scanner and an inertial measurement unit, which provide to the robot the capability of navigating and localizing itself in the agricultural environment.
To start the experiment the vehicle is placed before the beginning of an orchard row, then it has to detect the latter, navigate through it keeping a fixed lateral distance from the trees and stop the navigation once it has exited the row.
In order to achieve this goal, algorithms for the detection of beginning, end and direction of rows are implemented, exploiting the semi-structured nature of orchards. These tools are seen as fundamental capabilities for smart navigation in agriculture.

I. Introduction

A. Background and Motivations

Since many years different works have appeared for the purpose of autonomous navigation within rows, nurseries and orchards. The first who began to address the problem, like Billingsley and Schoenfisch (1995)-[4], used vision guidance systems in order to follow rows in crops such as cotton. Researchers like Bjorn Astrand and Albert Jan Baerveldt (2005)-[1]- introduced a new method for robust recognition of plant rows based on the Hough transform using a video camera. Moreover, a stereoscopic vision was used by M. Kise and Q. Zhang (2005)-[6]- to create an elevation map in order to identify the crop rows. In this work primary sensor for detection rows is a 3D laser scanner. Laser range finders started to be used in robotic environment for their countless advantages. Compared to cameras, laser tecnology allows to directly detect distance from obstacle and do not depend on lighting conditions. A. Kinchener and Th. Heinrich (1998) -[5]- mounted a LADAR in the front bumper of a car-like vehicle at a height of 68 cm and used different types of image processing algorithms for recognition of road boundaries. Furthermore, laser scanners were used also to detect obstacles (Ewald and Willhoeft 2000)-[8] and in some cases video cameras and laser sensors were fused in order to achieve an enhanced environment estimation (Labayrade 2005)-[7]. In recent years Bergerman and his team used a laser scanner and Hough transform algorithm to estimate orchard lines and control an autonomous vehicle. Towing various types of equipment that rover could perform different tasks, like mowing an orchardblock and spraying weeds (Hamner, Singh and Bergerman 2010)-[2].

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B. Background and Motivations

The experimental platform used in this work is a tracked rover, which differs from classical wheeled vehicles. One of the main benefits is that tracks allow better weight distribution respect to wheels. This peculiarity allows tracks to succeed in improving the adhesion to the ground in case of mud, puddles or friable soil. Moreover, the kinematic of a crawler is similar to the unicycle model, meaning that it can steer on itself and, with respect to a car-like vehicle, it can invert running direction without changes in the steering behaviour. Principal sensor mounted on-board is a 3D laser scanner (Lidar VLP-16). The advantage of the 3D configuration is the possibility to consider distances at different heights, adapting the system to various kind of rows, and to recognize the 3D shape of obstacles.

II. Vehicle Description

A. Mechanical subsystem

Fig. 1: Agriculture UGV used for experimental tests.

Agriculture UGVs have to perform several types of tasks within an orchard, such as mowing, spraying, watering, etc. But all these different jobs share a common feature: the capability of moving autonomously along orchard rows, ensuring high robustness to uneveness of the terrain. Due to this, the first decision that have been faced in developing a physical platform has been the motion mean, namely whether wheels are better than tracks or not. As shown in Fig. 1, the chosen platform is a tracked rover, since tracks ensure an higher level of stability, in particular in bumpy environments like the farm is; furthermore the contact surface between the bottom part of tracks and the ground is higher than the one of wheeled vehicles, ensuring an increased level of traction which is a relevant features in this working environment.

The rover dimensions are $1.2m$ of length, $0.6m$ of width and about $1m$ of height, while the total weight is about $100kg$.

B. Electrical subsystem

Actuation of the motion is entirely achieved via electric DC motors, whilst the power supply is provided by a couple of lead batteries.

Due to the need of performing autonomous navigation, the rover has been equipped with a suite of sensors, endowing the capability of local and global position and attitude estimation. The onboard sensors are a Differential GPS receiver, for global positioning, an Inertial Measurement Unit and a 3D Laser scanner, for environment detection and local positioning.

C. Software subsystem

The rover is completely controlled by the onboard computer, which is placed in the electronic box and provides for sensor reading, data processing and calculating the motor reference velocities (Control system). On the PC is also implemented a Human Machine Interface (HMI), by which the user can monitor the system during the operations and assign both missions and commands to it.

1) Human Machine Interface: The user interface, run on a Windows operating system, presents a Google-like satellite map (see Fig. 2), where the operator can monitor the rover position, and a series of labels and buttons, by which he can see the connection and mission state as well as interact with the rover. In particular, he can start the system by connecting the joypad (useful to regain the control of the robot in case of emergency) and begin the communication with the motors and the control system. Once the system is started, a bidirectional communication with the rover is available and the user can send missions or tests to the robot (in the form of command messages) and see the position of the rover and the state of the mission.

2) Control system: This subsystem is implemented in ROS (Robot Operating System) and executed under a Linux operating system. In this environment, a series of executables (ROS nodes) provides the position and attitude estimation, the mission management and the autonomous navigation in the rows (see Fig. 3). The Pose Estimation (PE) node reads data from the IMU, the GPS and the laser scanner in order to estimate the position and the attitude of the robot, while the Row State Machine (RSM) implements the state machine that handles the mission: it interprets the user commands, computes the trajectory of the rover through the

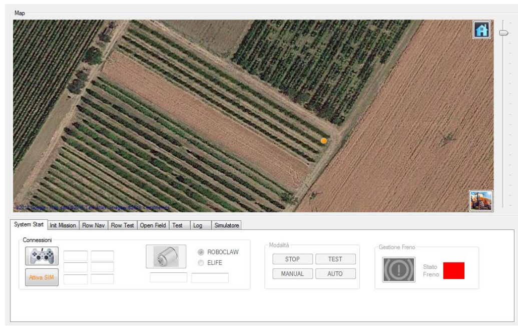

Fig. 2: Main window of the HMI, with the orange dot indicating the rover position in the map

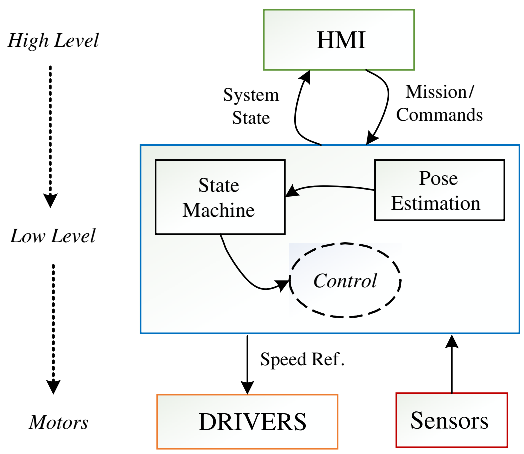

Fig. 3: Blocks scheme of the software architecture

rows and recalls the elementary control function that allows the rover to navigate within the rows. The communication between the two sides of the software subsystem is realized by the exchange of UDP messages, encoded according to the standard Mavlink protocol and sent through the network connection.

D. *Position estimation and feedback control*

During the navigation between the rows, the robot doesn't need to know its global position, but the relative one with respect to the environment. Thanks to the row structure of the fields, where the trees are aligned and the different rows are parallel and placed at a fixed distance, the only information that the rover needs is lateral distance, i.e. its position with respect to the lines of trees. For this reason, the developed navigation system is based on the estimation of two parallel lines, which identifies the rows.

Let us start from a simple differential-drive model [3] of the rover kinematics

$$\begin{bmatrix} \dot{x}_I \\ \dot{y}_I \\ \dot{\psi}_I \end{bmatrix} = \begin{bmatrix} \cos\psi_I & 0 \\ \sin\psi_I & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} \tag{1}$$

where (x_I, y_I) is the position of the rover in the inertial frame, ψ_I the attitude of the rover (i.e. the yaw angle) and (v, w) are the inputs of the model, representing the translation and rotation velocity, respectively. Let us assume that the orchard rows are represented, in the inertial coordinate system, by straight lines

$$y = n + \tan\psi \tag{2}$$

where n and ψ are constants. Now the distance from the orchard rows can be defined as

$$d = \frac{y_I - \tan\psi - n}{\sqrt{1 + (\tan\psi)^2}} \tag{3}$$

while the relative angle between rover and row lines is $\theta = \psi_I - \psi$. After some mathematics, model (1) can be rewritten in local coordinates as

$$\begin{bmatrix} \dot{d}_i \\ \dot{\theta}_i \end{bmatrix} = \begin{bmatrix} \sin\theta_i & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} \tag{4}$$

with $i \in \{r, l\}$ indicating right and left side respectively. The lines estimation algorithm exploits the Hough transform, which works on the 2D laser scanner data and provides a distance d and an inclination θ between the body reference frame (x_B, y_B) and every estimated line (see d_r, θ_r and d_l, θ_l in Fig. 4, representing distance and inclination of the right and left line, respectively). Finally, these data is filtered and used as feedback information, in order to close the loop of the row navigation control.

Usually, in the agricultural work, the tractor is driven imposing a constant low translation velocity and the steering is periodically corrected, in order to avoid obstacles and maintain the center of the row. Following this approach, a constant velocity v is asked to the robot, while the rotation velocity w is controlled by the algorithm and treated as

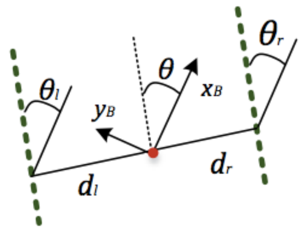

Fig. 4: Distances and angles provided by the line estimation algorithm

control variable for the navigation in the rows. The regulator of this control loop looks like

$$w = \frac{1}{v \cos\theta}(\ddot{d}_R - k_p(d - d_R) - k_d(\dot{d} - \dot{d}_R)) \quad (5)$$

where θ and d are the angle between the rover longitudinal axis (x_B) and the row line and the distance from the rows, calculated as a combination of (θ_r, θ_l) and (d_r, d_l) given by the row estimation algorithm, d_R is the desired lateral distance and k_p and k_d are the proportional and derivative gains. Furthermore, the distance derivative $\dot{d}$ is estimated from the distance d. As previously mentioned, in this application the rover has to navigate at a given lateral distance from the rows, in order to perform certain tasks, meaning that the lateral distance reference is constant and leading to $\ddot{d}_R \equiv \dot{d}_R \equiv 0$.

III. Experimental tests

A. Goals and esperimental setup

Some experimental tests were carried out in the countryside, in order to validate the developed architecture and control algorithm. The aim of those experiments was quite simple: making the rover navigate itself within two rows of trees. The test started with the rover placed at the beginning of the row. Once the rover detected the two lateral rows, i.e. it recognized to be inside the rows, it started to navigate. The aim of the controlled system was to move from the beginning to the end of the row, maintaining a certain lateral distance. The latter is a mission parameter, imposed by the operator, which could ask the robot to stay in the center of the row, or closer to the left or the right side. The test ended when the rover detected the exit of the row and it stopped. In details, the goal of the experiments was to test:

- HMI and control systems, in terms of architecture, and the communication between the two parts, i.e. the capability of the robot to receive a mission, to perform it and send the system state to the HMI
- Estimation of the lines of the rows of trees, used as a lateral distance measurement and a feedback for the navigation control loop
- Detection of the beginning and the end of the rows
- Row navigation control, which computes the velocity references for the track motors and which has to maintain the rover at a given lateral distance from the trees

In order to consider different kinds of environment, the system was tested both in a plum field, with a lush vegetation, and in a vineyard, with young plants and a very little foliage.

B. Experimental results

During the experiments the HMI, the ROS system and the communication systems behaved very well. There were no loss of data, no crashes of the code and no problems in the mission assignment and system monitoring, for the whole work time. The lines estimation worked well, both in the plum field and in the vineyard, demonstrating that such a kind of environment estimation strategy is efficient and can be applied to exploit the row structure. Fig. 5 and Fig. 6 report the screens of the estimated lines during the tests in the plum field and in the vineyard, respectively. These two figures show the good results obtained through the lines estimation, which is correct in both the situations.

Previously, the detection of beginning and end of the rows was tested separately from the rest of the system, in order to create different conditions for the algorithm. The results, both in the first tests and during the navigation mission, were good. The algorithm recognized the entrance or the exit from the row, with no false positives or false negative. Finally, the row navigation control was tested in the vineyard, performing the mission described in section III-A. To give an idea of the results, during the experiment, the GPS positions of the rover were periodically saved and showed in the HMI map. After a certain amount of time, the result is a

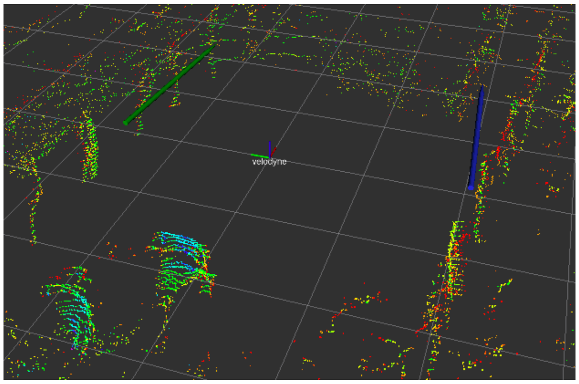

Fig. 5: 3D laser data and lines estimation within the vineyard

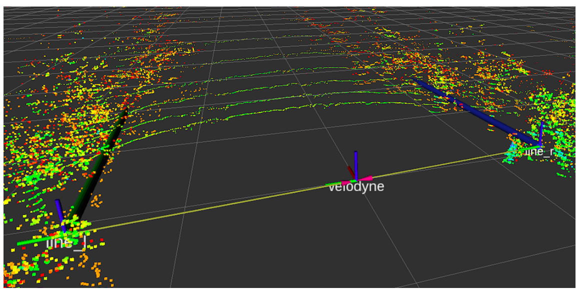

Fig. 6: 3D laser data and lines estimation within the plum field

Fig. 7: Trajectory of the rover during the autonomous navigation

series of icons that represents the trajectory of the robot during the autonomous navigation (see Fig.7). Looking at the route of the rover, one can see that the center of the row is maintained with a good precision, with little oscillations due to protruding branches or differences in vegetation luxuriance.

IV. Conclusion

In this paper, a description of the developed agricultural tracked rover and some first practical results were given. The carried out tests showed that the developed robot and its different parts work and interact together in an efficient way. Likewise, the estimation of the surrounding environment and the navigation within the rows gave positive results. The next steps towards the improvement of the systems are both theoretical and practical. From a practical point of view, the idea is to carry out more outdoor experiments, in order to better validate the algorithms and the developed architecture. Then, in order to expand the functionalities of the robot and the missions that can be covered, the team is trying to establish a new approach to the autonomous row change problem. Once this new block will be added, the robot will be able to automatically navigate in a whole vineyard or field without the intervention of human operators.

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