An autonomous mobile manipulator for pheromone dispenser deployment in vineyards

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***Abstract*—Field robotics is a fast developing research field, in particular precision agriculture is gaining in popularity due to the high return in productivity and the reduced pollution impact on the environment. The GRAPE project is an ECHORD++ robotic experiment aimed at the use of a mobile robot for automatic pheromone dispenser distribution in vineyards, to reduce pesticide use thanks to pheromone mate disruption. For the specific scenario a real state of the art does not exists, so we adapted techniques that have been designed for different problems, in particular classical methods for navigation and mapping in indoor environments and visual servoing techniques for manipulation and pheromone deployment. While navigation can leverage on standardized tools from mobile robotics, i.e., grid mapping and sensor fusion, manipulation still presents open challenges. In this work we describe the overall navigation system and the tools designed to manipulate small and flexible objects based on visual servoing algorithms.**

***Index Terms*—Precision farming, agricultural robot, image based control, dispenser grasping and deploying**

I. Introduction

The GRAPE project (Ground Robot for vineyArd monitoring and ProtEction) addresses the agricultural and food robotics scenario, focusing on vineyard farming activities and aiming at executing vineyard monitoring and pheromone dispenser deployment tasks with a mobile manipulation platform [1]–[3]. The project aims at developing technologies that can contribute to the technical advancement of precision agriculture, the most effective way to significantly reduce the negative environmental impact of farming.

The main objective of the project is the development of an Unmanned Ground Vehicle (UGV) able to autonomously navigate on rough and sloping terrains to collect data, to be used by the agronomists to analyse the status of the plants, and which is also able to perform simple farming tasks, like pheromone dispenser deployment. Indeed, in agriculture, robots are mostly used for crop monitoring, like aerial inspection for growth control, but heavy tasks like pruning, seeding or even precise harvesting could be faced by an autonomous mobile manipulator as well.

Autonomous robot navigation in vineyards differs from indoor navigation or autonomous on-road driving, consequently the architectures traditionally adopted do not represent necessarily a viable solution. A vineyard scenario is characterized by some peculiar features, such as soil, weather, and vegetation, which drastically complicate the robot perception, by introducing noise in sensor readings. For instance, soil affects the motion of the robot and it is responsible for wheel slippage and robot platform tipping and rolling. To cope with these issues we have employed a multi-sensor navigation system which takes advantage of a sensor fusion framework to fuse measurements from wheel encoders, IMU (gyroscope, magnetometer and accelerometer) and GPS.

Fig. 1: GRAPE robot.

Manipulation in field robotics has not reached the maturity of its industrial couterpart; uncertainties in positioning and the unstructured environment challenge manipulation in field robotics. The procedure we have developed for the pheromone dispenser deployment is composed of a grasping and a deploying phase, in both cases a visual servoing control strategy is used to cope with the low accuracy and repeatability of the arm, and the variability of the external environment. A feeder, placed on the platform, keeps dispensers open so that they can be easily taken one by one by the robot and robot fingers have been equipped with nails able to robustly grasp and hold pheromone dispensers during the operations.

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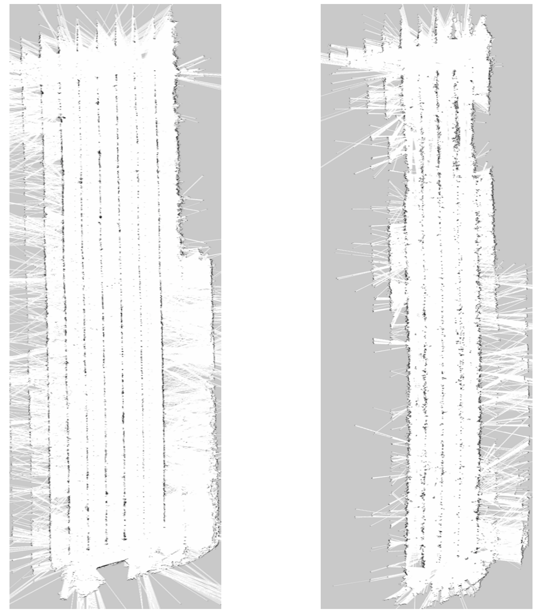
Fig. 2: The vineyard used for testing



(a) (b)

Fig. 3: Maps from Winter (a) and Summer (b) field tests.

II. GRAPE AUTONOMOUS NAVIGATION SYSTEM

Being in the contest of field robotics, the aim of our navigation system is to be innovative, if needed, but most of all it has to be reliable since it must guarantee to work in a difficult scenario like the vineyard one. We then designed our system based on a simple, but very stable solution, i.e., the ROS navigation stack, and we configured and validated each of its components via field trials.

A. GRAPE mobile platform

The GRAPE robot (Figure 1) is a skid-steering four wheeled mobile robot based on the Husky platform[1]. It is equipped with a frontal Hokuyo laser range finder, a Velodyne Puck, a common PC with WiFi module, and an IMU sensor. In addition, the rover mounts a robotic arm, a Kinova Jaco2[2] which incorporates a low range Hokuyo, and a vertical support for the GPS antenna and a Zed stereo camera. The Husky platform has been selected for the experiment being designed to operate outdoor, resistant to different weather conditions and equipped with four knobby wheels with a skid-steering kinematics that are suited for rough terrain navigation. Its body shape allows for customization while it is easy to transport thanks to its limited weight and size. Finally, the Husky platform is provided with an updated open-source repository in which the ROS packages implementing all the basic functions of the robot are stored and maintained by the robot producer.

B. Sensor fusion odometry estimation

Odometry estimation depends on the quality of the measurements coming from the motion sensors. In our case the variability of the environment introduces a significant amount of noise in these measurements. For this reason, we adopted a sensor fusion approach in which we exploit the wheels encoder, the IMU, and the GPS sensor all together. We implemented and compared two different sensor fusion tools testing different sets of sensors. The first implementation of the sensor fusion odometry estimation module was based on the robot_localization package which merges the wheels encoders readings and the IMU, but this was not reliable since it accumulated error constantly during time. To solve this problem, we introduced the GPS readings in the sensor fusion, obtaining an important reduction of the error due to the periodic correction made by the GPS. This solution, being EKF-based, is computationally very efficient and it proves the importance of the GPS in obtaining accuracy and a good reliability.

C. Mapping

In the GRAPE experiment we expect to map the vineyard once and then let the robot navigate autonomously with its support. During the mapping the robot is manually driven along the vineyard rows. Then a SLAM software is used for map reconstruction. As mentioned in the previous sections, we built the robot odometry based on multiple sensors obtaining a reliable and accurate positioning of the robot. This allowed us to reuse methods for indoor autonomous navigation also on the field, including a laser SLAM system. We compared three different SLAM tools: Gmapping, Google's Cartographer, and KartoSLAM The final solution we decied to use on the field, after evaluating the three methods, uses Gmapping since it has proved to have a good trade-off between reliability and resulting map accuracy. In Figure 2 the vineyard used for the field trials is shown and in Figure 3a. The main differences on the maps generated in Figure 3 come from the different vegetative state of the vineyard. In fact, in the first one there are no lives on the vines and only small weeds on the terrain, while when the robot was on the field, in Summer, the vines are full of leaves and the grass on the terrain is more developed. In addition the soil cohesion changes, causing robot wheels skid in a different way. Nevertheless we have been able to generate maps in both conditions as it was aimed by the project.

[1]http://www.clearpathrobotics.com/husky-unmanned-ground-vehicle-robot
[2]http://www.kinovarobotics.com/assistive-robotics/products/robot-arms

Fig. 4: The ISONET L E manufactured by Biogard.

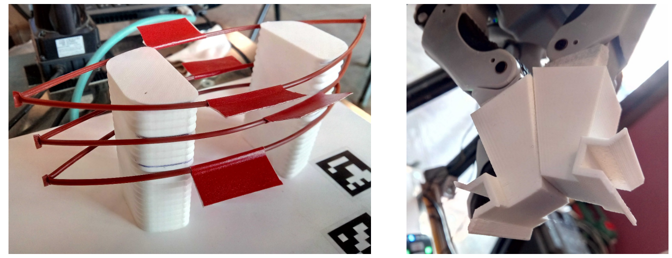


Fig. 5: Feeder and nails designed to manipulate dispensers.

III. GRAPE Manipulation System

The manipulation system has to perform three sequences of actions, i.e., grasping, manipulating and deploying a pheromone dispenser on a vineyard branch, that allows GRAPE robot to perform its main task. This manipulation task is completely decoupled from the navigation of the mobile base in the vineyard, indeed during the navigation phase the arm is kept in a safe position. Once the robot reaches a plant, the arm moves along a precomputed path to scan the vine using a laser scanner, and a 3D model of the plant is reconstructed. Analysing this geometric model the best point where a dispenser can be deployed is automatically determined and the deployment procedure is executed.

Grasping and deploying of pheromone dispenser tasks are executed following a simple common procedure. First of all, the arm is moved above the feeder where a RGB-D camera is used to determine the height of the first available dispenser, then a visual servoing controller moves the end effector into the desired grasping position. For the deploying procedure, three different strategies have been designed: (i) a simple position control to reach the target pose; (ii) a partitioned visual servoing controller based on information about the branch provided by the RGB-D camera; (iii) a visual servoing controller to deploy on a hook placed on a vineyard pole. Images provided by the camera are also used to check that dispensers have been properly picked up and released on the plant.

A. The GRAPE manipulator

GRAPE robot (Figure 1) is composed of an off-road mobile platform, a manipulator, and different sensors aiming at navigation, manipulation, and plant monitoring. The manipulator is a Jaco 2, manufactured by Kinova, a 6DOF lightweight robotic arm, made of carbon fiber and aluminum, with a weight of 4.4 kg and a reach of 90 cm. The arm mounts a 3-finger gripper and is characterized by a non-spherical wrist. The design of the robot, that includes the power electronics in the base, the possibility to power the arm with low voltage, and the low power consumption, make this robot the best solution for mobile robotics. The arm is equipped with a Sick TIM 571, a 2D lidar sensor for outdoor operation, and an Intel Realsense R200 RGB-D camera, that are used for the dispenser deploying task. In order to perform the deploying task Jaco 2 fingers have been equipped with tools that simplify dispenser grasping and manipulation.

B. Dispenser manipulation tools

A dispenser is composed by two flexible plastic capillaries, welded at the end, full of pheromones, with a length of approximately 15 cm. An example of these dispensers, the ISONET L E manufactured by Biogard, is shown in Figure 4. Pushing the two ends the dispenser can be deformed, enlarging the two capillaries, so that it takes the shape of a ring and it can be hang to a branch of the vineyard. The Jaco 2 manipulator, and in particular its hand, are general purpose devices not optimized for the specific application. Therefore, the length of the fingers is too large and the third finger interferes with, instead of aiding, the manipulation task. For all these reasons, we have designed a dispenser feeder, i.e., a device to store dispensers keeping them open so that they can be taken one by one, and ad-hoc nails, i.e., devices that are mounted on the fingers in order to make dispenser grasping operation easier and more robust. The design of feeder and nails has been targeted to the creation of tools that allow to increase the manipulation robustness being able to support a reasonable demonstration of the GRAPE robot functionalities. The feeder is characterised by a continuous vertical surface with a zigzag pattern, i.e., a saw-tooth profile. The zigzag pattern aims at introducing enough friction to hold dispensers in the desired positions while its small indents should not allow them to get stuck in the feeder during the detaching operation. Nails, on the other side, are characterised by a rectangular guide and two inclined edges. In the case of a small positioning error, this design eases dispenser entering inside the rectangular guide.

C. Grasping and deploying tasks

The aim of the arm is to provide the platform a set of services to perform vineyard scan, i.e., executing a predefined motion to detect the dispenser deploying location, dispenser deployment, and arm remote teleoperation. The dispenser deployment task is the most critical the arm has to perform due to the uncertainties in the position of the feeder and the deployment location, and to the elasticity/deformability of the dispenser that makes it an object difficult to be grasped and manipulated. The task has thus been decomposed into the following parts:

- feeder approach: a trajectory is planned from the current arm configuration to a pose close to the grasping zone;
- dispenser grasp: the grasping operation is performed using an eye-in-hand-camera and visual servoing;

Fig. 6: The hook used to deploy dispensers on poles.

- deploying location approach: the robot plans and executes a trajectory that connects the grasping zone to the deploying zone, i.e., near to the selected deploying location;
- dispenser deploiment: dispenser deploying can be performed using either position control or visual servoing.

Three different deploying techniques have been considered. One is based on the deploying point computed on the 3D model of the plant and uses only position control. The second one reconstructs the plant region around the deploying point using RGB-D data and drives the robot with a visual control approach. The last one, being the most "industrial oriented", deploys the dispenser on a hook placed on a vineyard pole using a visual servoing controller based on an ArUco marker as in Figure 6.

IV. Conclusions

In this abstract we have presented the results of the GRAPE project related to the grasping, manipulation, and deployment of pheromone dispensers. The overall system is based on a mobile manipulator able to navigate autonomously in a vineyard and to robustly manipulate flexible pheromone dispensers Results of experiments performed in a real vineyard during the final demonstration of the project show the effectiveness of the proposed system.

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