POLITECNICO DI TORINO

MASTER'S DEGREE IN MECHATRONIC ENGINEERING

GPS-based autonomous navigation of unmanned ground vehicles in precision agriculture applications

Author: Simone Cerrato
Supervisor: Prof. Marcello Chiaberge

Abstract. The global population is growing exponentially and the actual agricultural techniques and resources will not be able to feed every person on the Earth in a few years. To account for this serious problem, groups of research are focusing their attention on precision agriculture, because it looks for the improvement of the productivity and efficiency of both agricultural and farming production processes, while reducing the environmental impact, exploiting automation and robotics.
The thesis aims to design and develop a solution, based on GPS, for the autonomous navigation problem in precision agriculture, using only few sensors: an Inertial Measurement Unit, a GPS receiver and a depth camera, in order to be cost effective. The proposed goal has been achieved through a system of inter-operating sub-components, that have to share information and collaborate each other in order to provide a complete autonomous navigation. In particular, the main involved entities are: a localization filter, a global and a local path planning algorithms and an obstacle avoidance approach, that have been developed and can cooperate each other by means of the Robot Operating System.
Eventually, the proposed solution has been tested in a simulation environment, through different possible scenarios providing good results in each of them. However, it may be considered as a starting point for future improvement in the field of autonomous navigation for precision agriculture.

1. Introduction

Nowadays, the cooperation of newer technologies such as artificial intelligence and field robotics with older ones as the Global Navigation Satellite Systems allows improvements in the agricultural context, leading to the definition of precision agriculture. This relatively new term is mainly referred to the precise application of inputs such as water, chemicals and fertilizers to crops in order to maximize the yields while reducing the environmental impact. Moreover, precision agriculture exploits automation and robotics to increase the productivity and efficiency of agricultural processes as well as to reduce labor costs.
The thesis is focused on the GPS-based autonomous navigation problem in precision agriculture, in particular for vineyards. Two main starting points have been taken into account in order to look for a suitable solution:

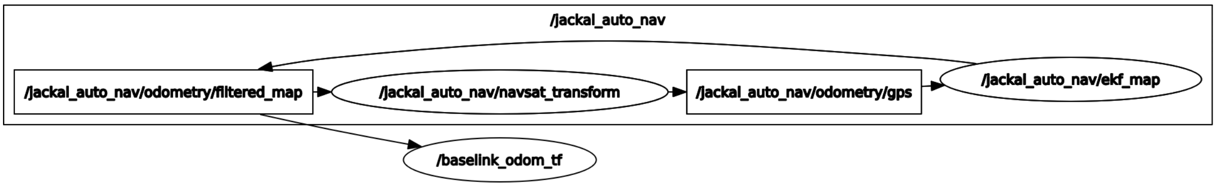


Figure 1. Robot localization nodes

- The availability of a global path, made up of GPS points, that has been computed exploiting georeferenced imagery.
- A local path planner, based on machine learning, that performs autonomous navigation inside vine rows, but it is not able to switch from a vine row to the next.

The proposed solution is based on the Robot Operating System (ROS) and is divided in three main components: a localization filter, a fake global path planner and an obstacle avoidance/local path planning algorithm.

2. Localization filter

The precise localization task is still now an open issue in field robotics and autonomous navigation systems, due to the uncertainties related to the estimation process. In this case, an Inertial Measurement Unit and a Real Time Kinematic enabled GPS receiver has been used to localize an Unmanned Ground Vehicle (UGV), in order to not add uncertainties due to the wheel slippage phenomena. The data provided by the two sensors have been fused together through an Extended Kalman Filter (EKF), in order to achieve a sufficient level of accuracy in the pose estimation process.
The Robot Operating System (ROS) offers a ready to use package, called *robot_localization*, that implements the EKF and transforms the GPS data into a ROS-compatible format. The Fig. 1 shows the main involved nodes (ellipses) and topics (rectangles) in the pose estimation process.

3. Navigation software components

The navigation algorithm has been developed exploiting the *move_base* ROS package, that is commonly used to perform 2D autonomous navigation in indoor environments. It is mainly composed by the following nodes: global path planner, local path planner, global costmap and local costmap. The four nodes are strictly correlated and have to exchange data, through topics, to achieve autonomous navigation.

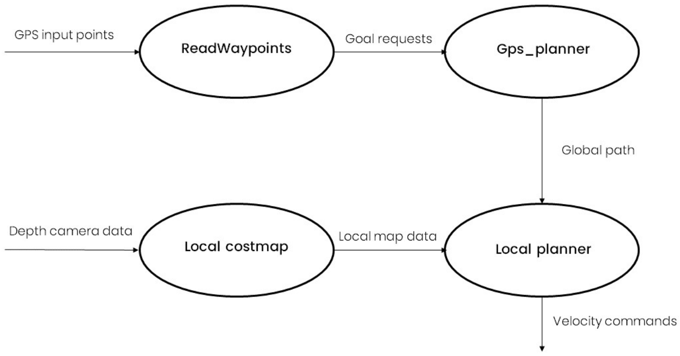
3.1. Fake global path planner

A global path made of GPS points is already available, as a consequence the global path planner and the global costmap of the *move_base* package have been replaced by a custom node, called *Gps_planner* in order to provide the right path to the local planner time by time, without implementing any global path planning algorithms from a start point to an end point. First of all, a custom node, named *ReadWaypoints*, takes as inputs the GPS route points, transforms them in map coordinates and makes a goal request to the *Gps_planner* node. Then, the latter builds a sort of global plan, made of a straight line, that connects the actual robot's pose to the received goal and publishes it on a specific topic. Eventually, the *ReadWaypoints* node waits until the provided goal has been reached, then it publishes another waypoint and the whole process carries on as far as all the GPS points have been visited.

3.2. Local path planning and obstacle avoidance

Once the global path has been published, the local path planner, based on the Dynamic Window Approach (DWA), looks for the best collision-free local trajectory taking into account the obstacles information coming from the local costmap node, the motion model of the UGV, the robot dynamical limits (e.g. accelerations, angular speed, etc.), the provided global plan and the goal. In particular, it generates a family of trajectories, sampling the velocities space (both linear and angular) of the robot within a short time interval and projecting forward the UGV's pose using such sampled velocities.

Then, each trajectory is associated to a cost, that is computed taking into account the distance from: the provided global path, the goal and the obstacles. Eventually, the local planner selects the minimum cost trajectory and sends the velocity commands to the platform specific controller, in order to make the robot move.



4. Simulation Results and Conclusions

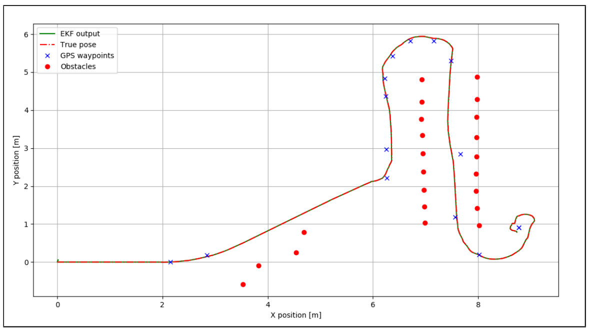


Figure 2. Results in the first simulation environment

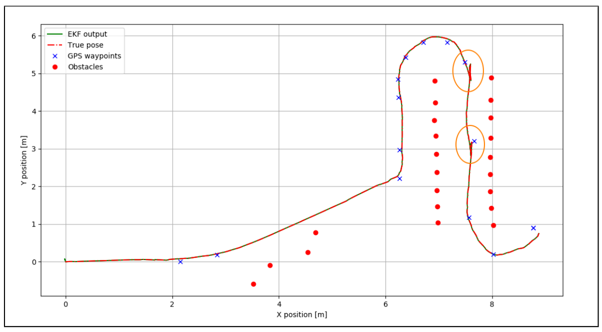


Figure 3. Results in the second simulation environment

Gazebo simulator and Rviz 3D visualization tool have been used to check the performances of the algorithms. Indeed the proposed solution has been tested through two different simulated environments. In both scenarios, the autonomous navigation system has provided good performances (as can be observed in figures 2 and 3) following the GPS route points, localizing the UGV in a quite accurate manner and avoiding the obstacles. However, in some cases the robot experiences difficulties to enter in the vine row due to the obstacles size increasing and/or it performs additional back and forth maneuvers to move away from obstructions (as highlighted with two orange ellipses in Fig. 3). Such minor issues can be easily solved by integrating and testing in a real scenario the provided solution with the local planner, based on machine learning, because it takes care of autonomous navigation inside the vine rows. All considered, the presented work can be employed wherever a global path made of GPS waypoints is available and can be seen as a starting point for future research in the field of autonomous navigation for precision agriculture applications.