Master Degree Thesis

Adaptation of a path planning algorithm for UGV in precision agriculture

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Path Planning

A great interest in self-driven vehicles has developed in the field of robotics and more generally in the industrial sector in the last few decades, and the number of applications where these vehicles are used is growing strongly.

In this context path planning algorithms play a central role in the architecture used for autonomous vehicles. Several analytical solutions to the problem of path planning have been made available in the last few decades, however, new applications and further improvements are still likely to be found since new, cheaper, more accurate and reliable tools are being constantly released. More innovative methodologies to represent the environment surrounding the vehicle were detected, thanks to the above mentioned tools with the consequent need to adapt the existing mathematical models to these new techniques.

Aim

The aim of the thesis work is to create a UGV (Unmanned Ground Vehicle) that can run independently, safely and efficiently through rough and uneven terrain, such as agricultural fields or unpaved roads, by using the RRT*(Rapidly-exploring Random Tree) path planner. The latter can accomplish its task also thanks to the collaboration with a UAV (Unmanned Aerial Vehicle) that, by means of the aerial photogrammetric survey method, can generate high-precision georeferenced orthophotos, that are later processed by a GIS (Geographic Information System) software to generate a binary static map, and a DTM (Digital Terrain Model).

In detail, the project is designed to cover different project phases. Starting from the design phase, when the criticalities of the problem are evaluated and possible solutions are identified, to the programming phase, in which a code for the planning of the route, adapting to the issues that may arise in this type of terrain, is developed, up to the simulation and real test phase in the field.

Main contributions

A superstructure was created around the main algorithm (the RRT*) for this type of application. This superstructure, allows the algorithm to work with the maps resulting from the innovative air-photogrammetric survey technique, minimizing the distance and at the same time evaluating how effective the path is, in term of slope, slope variation and roll.

The code dynamically explores most of the free configuration space to find a route through which the vehicle will reach the final position from the starting one. The path thus found is analyzed pose by pose, on the base of the above mentioned parameters, every 0.3 meters, making reference to the real point of contact between the vehicle surface and the ground, i.e. the wheels. By doing so, the code can examine whether to discard the newly-found route using the constraints entered by the user as evaluation criteria. This method of exploration is perfectly suited to sample-based algorithms, in which an implicit method of environment representation is used, i.e. determining whether a point in the configuration space is valid, using a black box function.

The code returns a series of waypoints as an output, and stores them in a text file that is then loaded on the Mission Planner software, generating the signals to send to the flight controller, on board of the vehicle, to follow the generated path as precisely as possible. The vehicle is equipped with two GNSS (Global Navigation Satellite System) systems, that can provide the precise position of the vehicle in real time.

Two types of simulations were conducted during the thesis work:

1. In the first one, the probability for the RRT* to find a path in three different scenarios was evaluated depending on which parameters are set into the code. The choice to perform this type of simulations was born when is noticed that the RRT* could not always find any path to traverse and that this behavior would have gratly affected the timing at which the code can provide a valid path, i.e. a path that falls within the imposed constraints.

2. The second one was carried out using the simulator on the chosen GCS (Ground Control Station), where the hypothetical behavior of the vehicle while trying to follow the waypoints on the field is simulated. This is done to configure the basic parameters of the flight controller so that the vehicle could follow the newly-traced path as accurately as possible.

Results achieved

The outcomes of the simulations of the first type, carried out in three different scenarios, lead to the conclusion that the parameters mostly affecting the search for a route, in environments with a high obstacle density such as a vineyard, are the distance between the poses and the inflation radius of the obstacles that in the most critical areas, i.e. between a row and another, has a huge impact on the probability of finding a route. This phenomenon is due to the bias method of the algorithm based on the k-nearest neighbor principle. For what regards the simulations of the second type, the basic parameters of the controller were refined so to have an average distance value of 0.11 meters, between GPS points and waypoints, with 0.068 meter standard deviation.

The validation was carried out in the airfield of Tetti Neirotti near Rivoli (TO) and highlighted several problems regarding the controller parameters and the limits of the chosen vehicle, in particular. During the tests, in addition to the tools on board, a total station was also used to have an external reference to track the position of the vehicle.

The most important changes regarding the controller parameters were those made on the derivative and intregative part of the steer PID regulator and on the lateral acceleration control period that heavily influenced the steering control of the vehicle, outlining a continuous zig-zag pattern even on a straight route as the controller tried to continuously correct the trajectory.

Another parameter that was also changed is the navigation speed of the vehicle that shifted from 1 m/s to 1.5 m/s, and this has become essential due to the vehicle's difficulty to maintain a constant 1 m/s speed during navigation. This factor heavily influenced the final result, especially during curves. In addition, a problem with wheel camber was also noticed, because of the fully discharged shock absorbers, which lead the vehicle to skid to the right during what should be a straight line. The path taken during the tests is visible in Figure 1, where the following elements are reported, in order: the trajectory calculated by the EKF (Extended Kalman Filter) of the Pixhawk, the trajectory actually traveled according to the total station and the ideal waypoints provided by the algorithm. The best results that were obtained during a single day of testing are reported in Table 1.

Table 1: Test 3 trajectories error evaluation.

Compared cloud	**Mean Distance**	**Standard Deviation**
Total Station VS EKF POS	0.294 m	0.301 m
Ideal WP VS Total Station	0.384 m	0.451 m
Ideal WP VS EKF POS	0.283 m	0.347 m

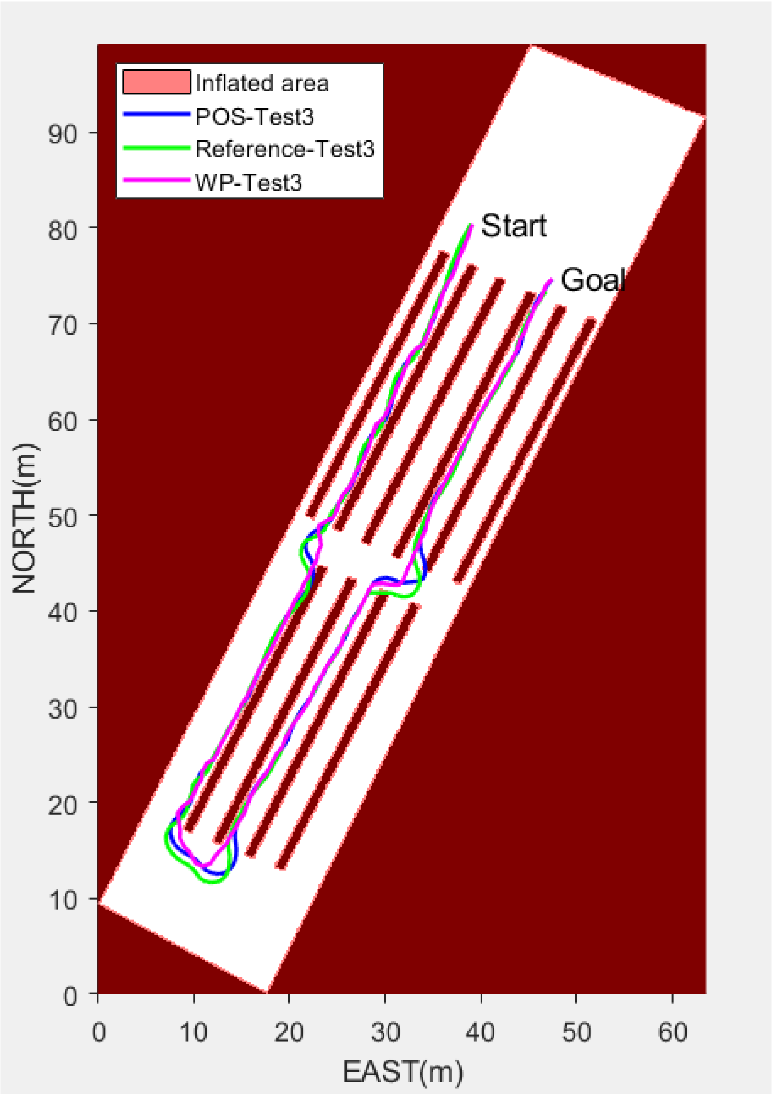

Figure 1: Test 3 Total Station, EKF and Waypoints trajectories plotted onto the binary mask with the presence of virtual rows.