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Algorithms, for path following and planning, for agricultural robots.

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Abstract: The basis to perform any agricultural task by robots is to planning and following paths or trajectories inside the crops. This research aims to developed and implemented algorithms for following and planning (global and local) trajectories for agricultural robots. The global planning was performed using the A * algorithm applied over crop maps and the local planning was performed using A* applied over a 2D map obtained from 3D images of the obstacles present on the way. Trajectory following, was done by implementing a numerical approximation of the trajectory by Euler's method. The parameters for the dynamics of the robot trajectory's controller were obtained by genetic algorithms. The 3D map was generated from the Microsoft Kinect sensor, and its data processed by Matlab 2010b. Preliminary results show that these algorithms can be implemented in small robots designed to be used in crop rows. Thereby providing a robust methodology to following assigned paths with errors less than RMSE= 0.1 m in trajectories of 30 m.

1. Introduction

Mobile robots needs to have a complete understanding of the terrain and features around it if it is to be able to navigate complex environments safely (Softman et al., 2006). Reason why, is essential to give it a safe path to follow, as well as sensors to detect and avoid unexpected obstacles.

In this research, we propose a set of algorithms aimed to solve the weeds control in row crops. In specific, we will address the path planning and following, soft curves generation to approximate these trajectories and finally, obstacles avoidance.

2. Materials and methods

As described in Correa and Vasquez, (2012), we will divide the methodology in three sections: a) Path Planning with A*. b) Trajectory smoothing. c) Trajectory Controller.

*2.1. Path Planning with A**

In the proposed scenario, the robot must go from its current position to the nearest weeds point. As a result, a planning to connect these two points will be performed. This planning is called Global Planning and is performed by A* algorithm.

Also, when the robot finds an obstacle a new planning will be performed. This planning is called Local Planning.

2.1.1 Global planning

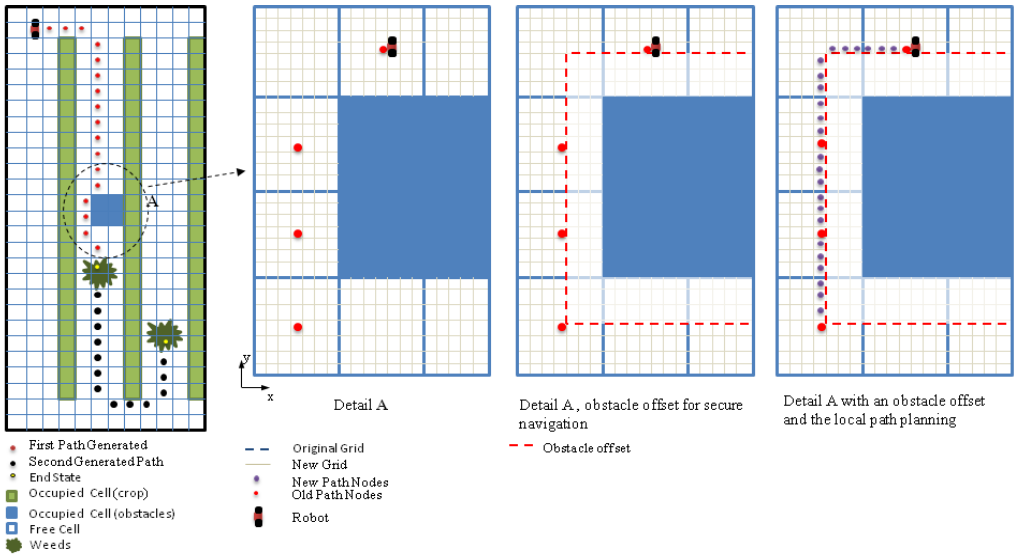
Assume that, the crop is divided into a grid and also that the robot is smaller than a square of this grid. We have three kind of cell in the grid: free, occupied by obstacles and occupied by weeds. A* is responsible of finding the shortest route between the current position and the nearest weed point.

Once the robot removes the weeds on the site, performs again the planning operation to reach the nearest weeds point.

In Fig. 1a shows in red dots, the robot trajectory from its initial location to the closest weed's point. Then, takes this point as starting point and creates a new path, marked with black dots, to the next nearest weed's point. This is a cyclical process in which it moves from between weed's points.

2.1.2 Local planning

When obstacles are detected by the Kinect sensor, a high-resolution 2d grid is generated as shows the Fig. 1b. Over this grid, is performed a local planning by A*, as shown in Fig. 1d and depicted in Correa and Vasquez, (2012).



a) b) c) d)

Fig.1. a) Paths generated by A*. b) Details of the global path to avoid obstacles. c) Security offset. d) Local path planning.

2.2 Trajectory smoothing

Once the global trajectory points are generated by A*, these points are connected by Bezier curves implemented by Casteljau algorithm as described in Choi et al. (2008).

2.3 Trajectory Controller

The trajectory controller proposed by Scaglia at al. (2006) was used and its parameters K_{ω} y K_{u} optimized by genetic algorithm as in Correa and Vasquez, (2012).

3. Results and conclusions

Several simulations, in three different scenarios, were performed for different path with and without obstacles, and its error measured by RMSE.

Scenario1. Showed in Fig. 2a, this scenario seeks to find the shortest path between the current robot position (coordinate [1.5, 18.5]) and the nearest weeds (coordinate [25.5, 13.5]) in a plot of 16 rows, spaced 2 m. This path has 30 m and was performed in 162 ms by an Intel ® Core 2 Duo 1.6 GHz.

Scenario2. Depicted in Fig. 2b, a plot of 11 rows spaced 3 m has 14 obstacles (Blue). The robot starts from the point [2.5, 12.5] must reach the weeds on the coordinates [42.5, 4.5]. In this case, the trajectory (84.4 m) is successfully generated in 238 ms.

a) Path length: 30 m. b) Path length: 84.4 m.

Fig. 2. a) Scenario 1, path between simulated vines rows (50x20m). b) Scenario 2, path between simulated obstacles.

Scenario3. In the case of unexpected obstacles, a 3D images of in field obstacles (previously stored), were randomly added as shown in Fig. 2b.

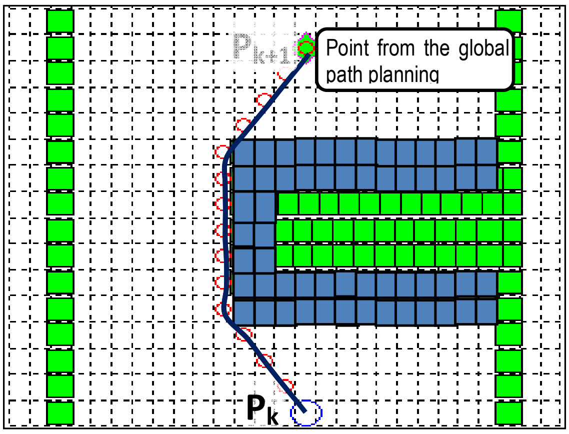


Fig. 3. Path for local obstacle avoidance and smoothing using cubic Bezier curves. ■ Offset of the obstacle.

3.1 Smoothing paths with Bezier curves. An example of the smoothing process is depicted on Fig. 4. This path is smooth and allows connecting points generated in the Scenario 1 in 340 ms.

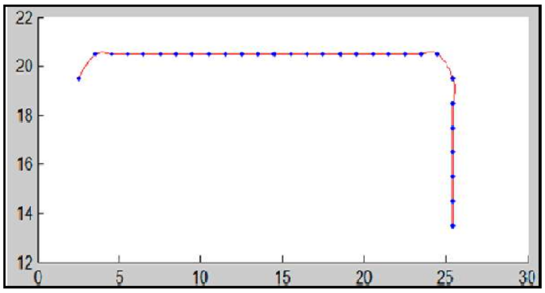


Fig.4. Smooth path using cubic Bezier curves, from Scenario 1.

3.2 Trajectory controller.

The Fig. 5a, shows the controller performance following the path (from the scenario 1) at desired speeds (0.2 m s^{-1}), using non-optimized controller parameters. The RMSE, is 0.54 m in this path of 30 m. However, the speed oscillated around 0.4 m s^{-1}, which is greater than 0.2 m s^{-1} of speed imposed as reference.

Note that the robot doesn’t reach its goal, and has many oscillations around the path.

Furthermore, when using optimal parameters, founded by Genetic Algorithm, the robot reaches its destination with a RMSE=0.15 m, and a maximum oscillations of 0.16 m, which guarantee a secure navigation.

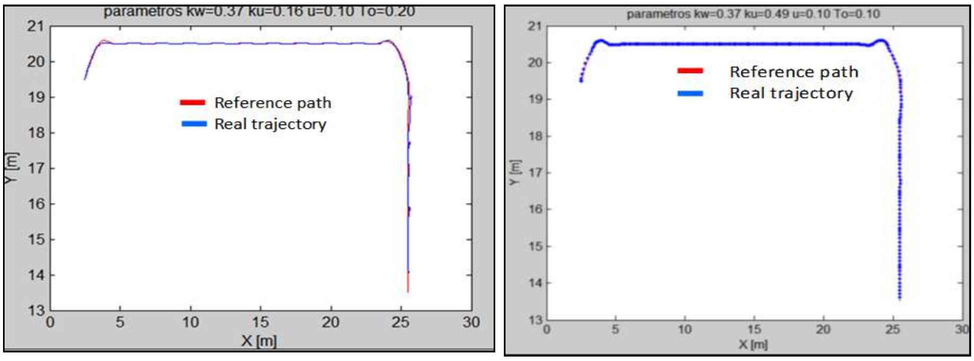


Fig. 5. Path following using controller parameters. a) K_ω and K_u suboptimal. b) K_ω and K_u optimal.

Additionally, the controller's performance is closely tied to the parameters K_ω and K_u. For our analysis the values selected are those that minimize the RMSE.

The behavior of our frameworks on different scenarios, to finds paths and generate trajectories is robust enough. Because, if a path to the goal exists, it guarantees to find an optimal path. But also, is efficient in terms of computation times.

The well proven A* algorithm, has shows its effectiveness in generating both local and global trajectories and their efficiency in terms of run times (<300 ms, for the longest path). Making it suitable to be used on agricultural robots.

Local obstacles avoidance based on Kinect sensor, is suitable for objects detection, even if they are small size objects. Kinect detect objects larger than 3 cm).

In addition, local obstacle avoidance is a reliable alternative. Because, while the robot has room to pass through, the A* algorithm, will find the lowest cost path. However, these paths tend to be closed curves, so it's necessary to reduce by half the robot's speed (0.1 m s^{-1}) in order to following closely the trajectories and prevent collisions in reduced spaces.

Finally, we think the greatest contribution of this work, lies in the integration of several techniques for: path planning and tracking, controller optimization and obstacle avoidance using 3D vision. Integration that, ensure an effective and safe navigation in agricultural environment. Combining classical techniques such as A*, with new tools as the Kinect sensor.

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