Navigation Techniques for Mobile Robots in Greenhouses

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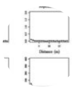

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NAVIGATION TECHNIQUES FOR MOBILE ROBOTS IN GREENHOUSES

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Abstract: This paper discusses the problem of using navigation methods for agricultural mobile robots in greenhouses. Nowadays, many agricultural tasks are dangerous and repetitive for human beings and could be improved employing robots. The autonomous navigation in greenhouses has been solved using both deliberative and pseudo-reactive techniques. The first one utilizes a based-on map algorithm to create a safe and obstacle-free path to travel. The second technique applies a sensor feedback algorithm to cross the greenhouse corridors. Both strategies have been implemented and tested in real environment, obtaining quite appropriate results. *Copyright @ 2007 IFAC.*

Keywords: Robotics, Agriculture, Mobile robots, Robot navigation, Path Planning.

1. INTRODUCTION

Nowadays, Agriculture constitutes one of the most important sectors and development source in many areas of the world. The Province of Almería (Spain) holds the largest concentration of greenhouses in the world (>27,000 H.), being one of the most important income source. It is needed to enhance productivity, looking for a better product quality and harvest opportunity, where technology plays an essential role in this adjustment process. Greenhouses require long hours of work, dangerous activities, and repetitive tasks, like harvesting, spraying, and farming. They decrease operation efficiency and could damage the operator's health.

Recent developments and advances in robotic field enable to apply mobile robots for greenhouse tasks which will not fatigue and can reduce operator's importance, improving the efficiency and operation safety. In order to make successfully greenhouse tasks through mobile robots, the first approach is to design appropriated vehicles to the structure and to the rough ground of the greenhouses. The second phase is to implement navigation techniques which permit to the mobile robot travel the corridors.

In previous works, it is possible to find some examples of mobile robots used in greenhouse tasks. (Mandow, et al., 1996) describes an autonomous vehicle (Aurora) for spraying tasks. The navigation control of this robot depends on a previous sequence of *behaviours* established by an operator, thus it does not employ strictly deliberative or reactive navigation techniques. (Sammons, et al., 2005) presents an autonomous spraying robot whose navigation control relies on inductive sensors which detect metallic pipes buried in the ground. An autonomous robot for harvesting cucumbers in greenhouses has been described in (Van Henten, et al., 2002), but unlike the previous reference, it is guided on the heating steel pipes.

A mobile robot, called *Fitorobot*, has been developed at the University of Almeria (figure

1), which permits the displacement between the lines of crop, and the performance of several tasks into the greenhouse like spraying activities, pruning, and crop transport. In a first approach, it has been equipped to make spraying activities (Sánchez, et al., 2006). Then a based-on map technique has been implemented for the autonomous navigation. This technique uses a map to calculate an obstacle-free path of the greenhouse before the robot travel it.

Fig. 1. Mobile robot Fitorobot.

Afterwards, an appropriate and low-cost sensor system was installed on the platform, and a pseudo-reactive technique was implemented to track the greenhouse corridors without a map. This technique is considered like *pseudo*-reactive because the navigation algorithm has been implemented knowing that there are parallel corridors disposed in rows into the greenhouses. Moreover, along the path a sensorial map is built, which will be used by the first technique in next runs.

The rest of this paper is organized as follows. The mobile platform *Fitorobot* is described in Section 2. In Section 3, we will discuss the design and the implementation of the deliberative and the pseudo-reactive techniques join to the sensory map building process. Experimental results are reported in Section 4 to show the performance of the different techniques. The conclusions are given in Section 5.

2. MOBILE ROBOT *FITOROBOT*

As figure 1 shows, the mobile robot *Fitorobot* has a rubber tracked system, which takes the advantages of differential drive vehicles and also provides a larger contact surface with the soft ground of the greenhouses, making it more robust and stable (Sánchez, et al., 2006).

This robot has a mass of 756 kg (with the phytosanitary tank full) and it has appropriated dimensions (0.7 x 1.5 m) to the corridors of the greenhouses. It is driven by a powerful 20HP gasoline engine.

It has also a low-cost sensor system including: seven ultrasonic sensors to detect distances from obstacles (three by each side and one front), one magnetic compass to control the vehicle orientation, two incremental encoders to know the angular speed and robot position (one by each axle), one radar to measure the linear speed, and security sensors around the vehicle to prevent the robot collides with the crop rows, with the walls of the greenhouse or with other obstacles.

The platform has been equipped with an industrial computer, with two additional input/output boards to receive data from sensor system and to send commands to the actuators (two hydraulic engines for the motion system and one proportional valve and two on/off valves for the spraying system). Software for data processing and control was developed using *National Instrument® LabVIEW®* and *MathWorks® Matlab®*. The programs have been executed to a sampling time of 100 ms.

3. NAVIGATION TECHNIQUES

Navigation is the key issue of mobile robots, and therefore studying the most appropriate navigation algorithm is the main stage to build a successful mobile robot. In mobile robotics there are two groups of navigation techniques, which are described briefly.

Deliberative techniques utilize a world model (map) to calculate a safe path between an initial point and a goal point. Models are typically either metrical or topological maps. Metric maps explicitly reproduce the metrical structure of the environment. Topological maps try to represent the environment as a graph. Reactive techniques do not require a previous environmental model. These strategies rely on sensor system to know the states of the vehicle, and to execute an action (Dudek and Jenkin, 2000).

Figure 2 shows the implemented navigation architecture in the mobile robot *Fitorobot*. This is a hybrid architecture, on one hand, the first time that the robot navigates the greenhouse if a map exists, it is employed by the deliberative method.

On the other hand (a map does not exist), the pseudo-reactive method is used. Moreover along the path a sensorial map is built, which will be employed by the deliberative module in later runs. These methods also utilize low-level layers which help to avoid collisions and a low level control layer, which control that the references are followed by the actuators.

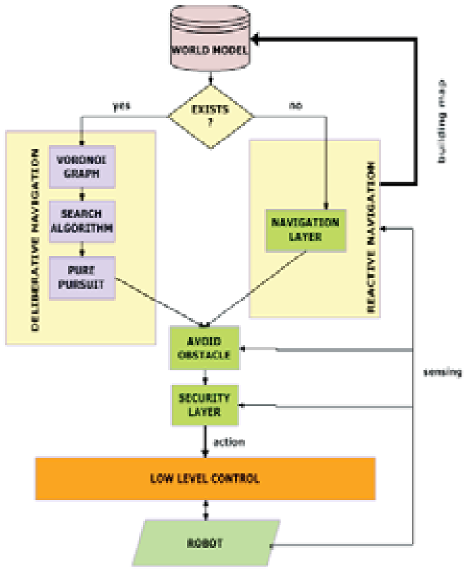

Fig. 2. Hybrid architecture for navigation.

3.1 Deliberative technique

Greenhouses are built using digital maps. These maps could be used by robotic navigation algorithms to control and steer vehicles.

The selected path planning algorithm has been a modified *Voronoi Diagram*. It is defined as the locus of points equidistant from the closest two or more obstacle boundaries, including the workspace boundary. The set of points in the *Generalized Voronoi Diagram* has the useful property of maximizing the clearance between the points and obstacles (Choset, et al., 2005). Once, the Voronoi algorithm is applied to a greenhouse map (figure 3) should be employed an algorithm to eliminate the edges inside of plants.

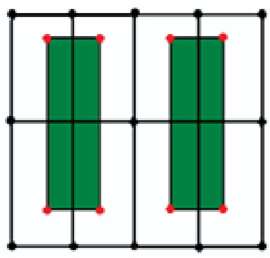

Fig 3. Voronoi 's algorithm applies to a greenhouse.

Subsequently, a search algorithm is needed, to find the minimum distance path between an initial point and a final point, and this path does not have to leave any corridor untracked. A typical search algorithm is *Dijkstra* (Berg, et al. 2000), but is not appropriate because any corridors would be untracked (dotted blue line in figure 4). The red line in figure 4 shows which is the most appropriate and desired path. Therefore, a new search algorithm has been implemented to obtain the minimum path which permits to the robot navigate all corridors (figure 5).

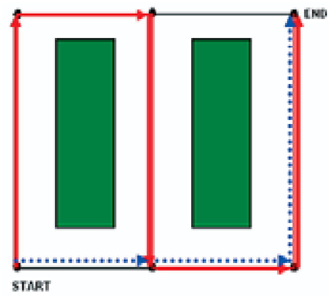

Fig. 4. Navigation path inside greenhouse.

Building a path similar to the desired previous path in the figure 5 is easy, knowing the coordinates of the vertexes in the graph, the start point, and the end point. Then, the desired path will start in the vertex with minimums values of x and y. The next step is to obtain a greater or lesser value in the *y-component* and when it is not possible, to obtain a greater value in the *x-component*. The obtained path should be sampling depending of the desired speed to perform the task.

Irrespective of obtaining the path to follow, it is needed to implement an on-line technique that permits calculate in real time the references for the engines and the robot follows the planned path. The selected algorithm has been the *Pure Pursuit* (Coulter, 1992). This method utilizes the kinematic model, and generates the linear speed for the engines in every sampling period.

3.2 Pseudo-reactive technique

Currently, a lot of mobile robots which utilize reactive navigation strategies mainly use algorithms like bug, potential field (Shimoda, et al., 2005) and analogous. These methods are not suitable for navigate greenhouses because they could leave some corridors untracked.

In order to avoid this problem, a new pseudo-reactive algorithm has been developed. This algorithm does not need any previous map and will be feedback by the sensor system described in section two. The navigation algorithm is composed of a set of basic behaviours such as: go straight, turn left, turn right, and stop.

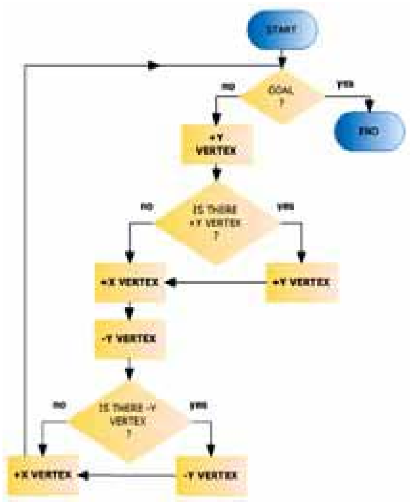

Fig. 5. Search algorithm implemented.

Figure 6 shows a typical structure of a greenhouse. It is possible to observe that when the robot is at the end of a corridor, it could turn to the left or to the right side. This decision will be taken relying on the sensor system and the previous turn.

Fig. 6. A typical Mediterranean Greenhouse.

The key idea is that the second turn will be to the same side that the previous one. When it has turned two consecutive times the next two turns will be to the opposite side. The sensor that controls the turned angle is the magnetic compass and the robot stops when the value of compass changes 90 degrees. Furthermore, the front sonar value is used to adjust the vehicle speed, in order to avoid that the vehicle suffers sudden stops. This algorithm is called *pseudo-reactive* because the mobile robot trajectory is known but the free path in the greenhouse is unknown.

It is important to note that the real corridors of greenhouses are not perfectly straight and have not the same width. Whereby, we have implemented a centering and an inclined-corridor process.

Figure 7 illustrates the centering process. Firstly, the situation is detected with lateral sonar. Then the robot turns to the side which the lateral sonar values is higher (step 1), later it goes straight (step 2), and finally turns to the opposite side than the previous turn (step 3).

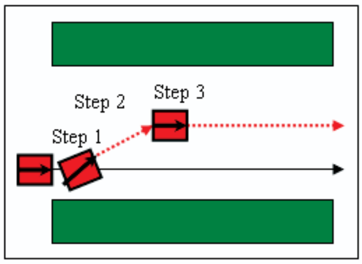

Fig. 7. Centering in corridor process.

The inclined corridor situation is showed in figure 8. This situation is presented when the front lateral sonars have different values that the back lateral sonars. The robot will turn to the side where the front sonar has a higher value.

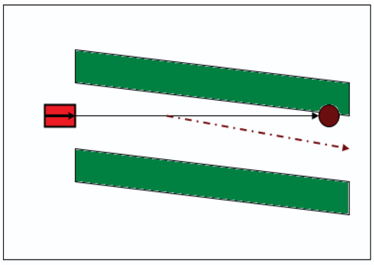

Fig. 8. Inclined-corridor process.

Analyzing the sensor readings in a real environment is possible to observe that sometimes these data produce peaks. These peaks are produced because the sonar beam slips in the vegetal mass. Although, these data are attenuated combining the readings of all sensors, a filter has been studied and implemented to attenuate these peaks. This filter is based on compare the current reading with a previous values window, and if the current one differs a greater quantity than a threshold with the middle of the window size, the current reading changes its value to the value which the difference is greater (eq. 1).

$$\xi = [\sum_{i=k-1}^{k-n} \Gamma[(s_k - s_i) < \varepsilon]] > n/2 \qquad (1)$$

Being Γ: {true, false} → {0,1}, ε is a threshold obtained heuristically, n is the windows size, s_k the current data, s_i the window, and ξ is the condition change. If ξ is false the current reading is correct, else it is a peak.

Figure 9 shows the answer of the implemented filter (blue dotted line) with real data (red continuous line) in a real test along a corridor. It is possible observing that the peaks are quite well tolerated (the standard deviation of the filtered data is 0.68, while than in the unfiltered data is 2.17). This means that the filtered data are more homogeneous and therefore more appropriate to control the vehicle.

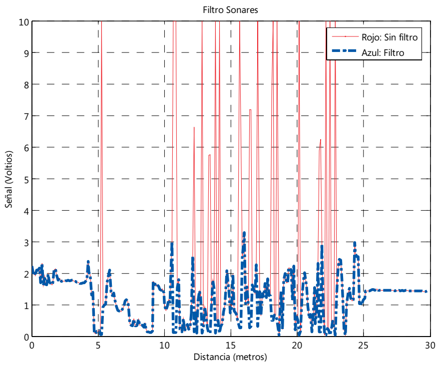

Fig. 9. Real test of the implemented filter.

3.3 Map building

Although currently many greenhouses have a digital map, rarely these maps are sometimes updated and numerous aspects of the greenhouse are not likely to appear on the map, such as: farmers, transitory objects, agricultural tools, etc. Therefore, a good solution would be to implement an algorithm which builds a map in real time, along the path of the mobile robot. (Fujimori, et al., 2002).

Join to the pseudo-reactive navigation algorithm, a method to build a sensory map has been implemented. The first step is to calculate the current robot position using the vehicle kinematic model. There are two ways: according to the encoder and the compass values, and using the radar and the compass values. Secondly, the sonar values are interpreted on the mobile robot reference system. The equation used to change the reference system is (eq. 2) which employs the angle (θ_{Sonar}) that every sonar has with respect to the platform and the calculated distance to the obstacle (d_{Si}).

$$x^{SRrobot} = x_{robot} - [d_{Si} \cdot \sin(\theta_{Sonar})]$$
$$y^{SRrobot} = y_{robot} - [d_{Si} \cdot \cos(\theta_{Sonar})] \qquad (2)$$

Being (x_{robot}, y_{robot}) the current position of the robot. The values of ($x^{SRrobot}$, $x^{SRrobot}$) build a bidimensional vector which will be the sensory map.

4. RESULTS

Two navigation techniques have been tested in a real environment using the mobile robot *Fitorobot*. The first of the experiments was following a straight corridor which had to the left and to the right plants. Afterwards, a new test was realized. In this test the robot left a corridor, turned and later returned to another corridor.

4.1 Pseudo-reactive navigation and map building

The first tested technique was the pseudo-reactive navigation and the map building algorithm.

Figure 10 shows the first experiment performed. It is possible to observe how the robot path is straight (red line) and the crop rows sensed by the sonars (blue asterisks) are the obstacles of the built sensory map.

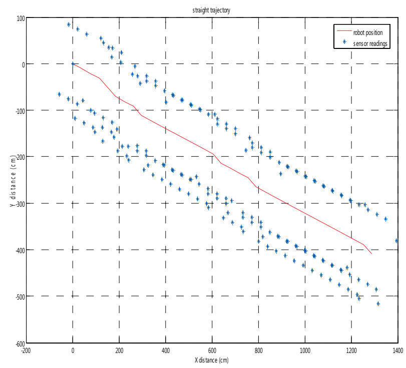

Fig. 10. Following a straight corridor and sensor-map built.

Later, the turn process was proved (figure 11). This figure shows how the robot turns twice to the right side when right lateral sonars are free, and when lateral sonars are occupied the robot goes straight.

In both cases, the maps are inclined because the initial position of the compass was 160 degrees.

4.2 Deliberative navigation

After the previous experiments were completed, the deliberative navigation algorithm was tested using the previous built map. The look-ahead distance used in the method of *Pure Pursuit* has been 1 meter.

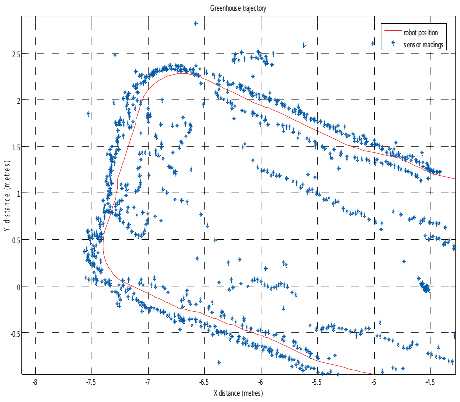

Fig. 11. Turn trajectory and sensor-map.

A turn trajectory was tested. Figure 12 presents the followed path by the robot (black line) and the reference trajectory (red line) obtained with the deliberative technique implemented. It is possible to observe that the error is less than ten centimetres.

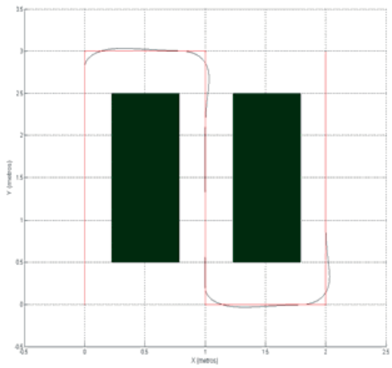

Fig. 12. Turn trajectory.

5. CONCLUSIONS

This paper addresses the performed work for getting a mobile robot to navigate successfully and safely a greenhouse. On one hand, a deliberative algorithm was presented. It needs a map of the greenhouse in which it goes to work. On the other hand, a pseudo-reactive navigation algorithm was described join to a sensory map building process. That sensory map will be employed by the deliberative technique in next runs. Finally, the algorithms have been tested in a real mobile robot, called *Fitorobot* developed at the University of Almeria in real greenhouses, obtaining quite appropriate results. The future work will consist in employing the robot for other tasks and applying artificial vision. Furthermore, a Kalman filter will be implement which will use radar, encoders and compass to estimate the robot configuration.

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