AUTONOMOUS VEHICLE FOR DOSAGE FERTILIZERS ON SMALL AND MEDIUM CROPS

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Abstract. *The high precision required in intelligent farming and the degree of technology involved, leading to high costs, up to now is only affordable just on large production environments; then there is still important to seek viable and cheap solutions for lower production in small crops. This article summarizes a design of a mobile robot for small and medium crops, autonomous navigation within a hectare of crop, making localized dosage of liquid fertilizers. The vehicle has a mechanical system type Rover of six wheels, with control motion system, path planning using A* algorithm, using a mapping system based on GPS limits on crop. Communication with the remote server is Zig-Bee type, with monitoring and dosing information storage of nitrogen, potassium and phosphorus fertilizers in variable rate, developed by Labview software. There was selected a pilot crop of high demand in Colombia of potatoes and built a 1:3 scale prototype for functional validation. The system makes the indicated dosage of fertilizers in controlled amounts for each plant and independently, with a maximum error of 3% by volume, which can be corrected by calibration system in field. Additionally, lifting and distribution limits of crop can be done with sufficient accuracy in small crops, but is strongly dependent on GPS accuracy.*

Keywords: *Precision farming, liquid fertilizers, path planning, autonomous vehicle, variable rate.*

1. INTRODUCTION

The increasing demand for food products in the world, requires a significant increase in agricultural production. Thus requires increasing in efficiency of planting and harvesting processes along with a significant increase in the yield per square meter. With this purpose, has been studied the application of autonomous systems in crops, mainly due to the shortage of skilled labor and the lack of mechanized production in the agricultural sector, especially in Colombia, where agricultural production is mainly familiar, using ancient crop methods in small rural areas.

In any type of production, it is desirable to look forward maximum benefit with minimum cost from better use of resources, as a key strategy to achieve maximum productivity, with the best product quality. For this reason, agriculture becomes more relevant every day, increasing the research in different fields related with the purpose of obtaining a high degree of production intervening soil and the environment as little as possible. For that, it requires the development and application of high technology to planning, production and automatic management of crops. That is called today as "*precision farming*" as Blackmore (2007). It allows maximum potential soil per hectare with less use of fertilizers, reduced land degradation and increased performance with lower production cost, using automatic equipment ,sensors (Christy, 2008; Vellidis , *et.al.*, 2008) ,detection systems (Bakker *et al*, 2008), global positioning systems (GPS) (Garcia-Perez, *et.al.,* 2008), positioning with digital correction (Gan-Mor, *et.al.*, 2007), geographic information systems (GIS) (Santé-Rivera, *et al,* 2008; Godoy, *et.al.,* 2010) ,robotic applications seed (Leemans and Destain, 2007), dosage and/or application of fertilizers (Yong, *et al.,* 2007), harvesting crops (Amiama *et.al.,* 2008), irrigation (Martin a *et.al.,* 2011) and weeding (Loghavi and Behzadi, 2008) among others. These systems are based on technologies to make a proper distribution of plants according to the physical, chemical and geographical, establishing the shortest paths generated by a computerized system (Caldas *et.al.,* 2008; Pajares *et.al.,* 2008), for a better utilization of the area, increased productivity and variable dosing fertilizers in a localized manner. Robotics Today is no longer focused solely on industrial applications, focusing also on development of vehicles (Paulsen *et.al.,* 2005; Thueer *et.al.,* 2006), systems applied in the field (Slaughter *et.al.,* 2008) and other complementary knowledge areas such as bioengineering and medicine, for example. Considering these needs, there was developed a robotic system that could move autonomously in an environment that simulates a plantation, avoiding any obstacles that may exist, and following the shortest possible path between the starting point and its destination. The complete system comprises a GPS measurement system for mapping boundaries with crop computer software which makes the reading and generate a

distribution of the crop in area mapped, in accordance with distance between plants and between rows, generating the coordinates of the control points on the robot positioning within that crop. With this information, using a computer application, for generation of trajectories for moving the robot automatically supplemented by a system for acquiring and storing information, through a wireless communication system, the control system of vehicle movement. It summarizes each of the systems developed and sets out the results of their behavior with positioning accuracy and NPK fertilizer dosage variable rate, obtained in performance tests.

2. DEVELOPED SYSTEM AND COMPONENTS

To develop the vehicle was necessary to determine the environmental conditions in which it should work, then there was defined a pilot crop to adjust the robot to its specific conditions as an example. It was selected a potato crops and autonomous vehicle has been designed from characteristics of this crop.

2.1 The GPS measurement system.

The possibility of developing a viable application for small and medium-sized plantations, is greatly supported by GPS measurement without data correction system (DGPS) or Real-Time Kinematic correction (RTK), but they require high precision equipment and cost, along with the permanent data service cost that means. Because of this, different GPS measurements made to establish the minimum requirements of the data and the possibility of making the mapping of boundaries with free GPS and then crop distribution and calculate the points of robot motion control into the crop with sufficient accuracy.

The measurements were performed with three GPS: one metric precision *GPS MAP 60CSx, GPS Geo Explorer 3* Sub metric accuracy and *dGPS for NXT* controller for ease of direct connection to the controller for storing data. That selection facilitated the definition of the coordinate measuring methodology for crop limits and minimum required positioning accuracy.

The measurements with GPS MAP 60CSx were taken every 15 readings averaged in the parking lot of La Salle University (Bogotá), on the sports fields represented in yellow in Fig. 1. Green, blue and orange are shown the results of the tests. The measurements showed positional errors up to 27 and 20 m North of its real position and from 9 m to the West. These errors due to difficult weather conditions GPS reading, along with multi-path errors, caused by proximity of a high church located next door at the bottom of the photograph. Likewise, the points with the lowest measurement error (Latitude 0 m in length and 0.6 m) are positioned in more open spaces. The measurements with the equipment Geo Explorer 3 Sub metric accuracy were taken every 100 readings averaged at intervals of reading every 5 seconds. Some points measured are shown in Fig. 1 together with the result.

Figure 1 – Images measurement data of La Salle University in Bogota, with *GPS MAP 60CSx* (left), sports field points measured with *Geo Explorer 3* (center) and the same points represented in the GIS Google Earth (right). (Google Earth Version 6.0.1.2032-beta).

Based on these results, other measurements were taken to see other greater contours accuracy in open spaces were tested. In Fig. 2 shows the measured data plots of Simon Bolivar Park at Bogotá of about 1200 x 600 m^2 and Cedro Salazar Park at Bogotá of about 400 m^2. The Geo Explorer 3 GPS did not measure nor send data to the computer in real time, using the same area it was used dGPS to improve compatibility with NXT controller used in the prototype vehicle on a small scale, it was generated a computer data file, to compare with GPS Geo Explorer 3, getting up to 2247 readings. These data were averaged for each point plotted and compared with the measurement errors. Fig. 2 shows the results for the twenty three (23) points representing the Cedro Salazar Park in Google Earth.

Figure 2. – Representation in Google Earth GIS data taken at Simon Bolivar Park in Bogota, Colombia (left side) with GPS Geo Explorer 3 and Cedro Salazar Park with Geo Explorer 3 in *average precision* (center) and Dexter dGPS (right side). (Google Earth Version 6.0.1.2032 - beta).

2.2 Mesh generation and positioning control points

Based on data reads by the dGPS and its file generated, it was programmed in Matlab software, application that reads the file extension "*.dat" generated dGPS and makes GPS coordinate conversion to metric distances, with the coordinate origin of the graph as the starting point of GPS measurement. These data are plotted and then corrected by a cycle of line approximation with cubic splines. The corrected data are the source of contour mapping information more accurately, to generate a crop distribution points and control points of the vehicle position for three different contours: 1) simple rectangular area, 2) regular polygonal area with straight sides, and 3) irregular polygonal area. Fig. 3 shows the original points measured with GPS and contour approximation method corrected with Cubic Splines, changed to local coordinates in meters from the start point highlighted with circle, for a completely irregular contour.
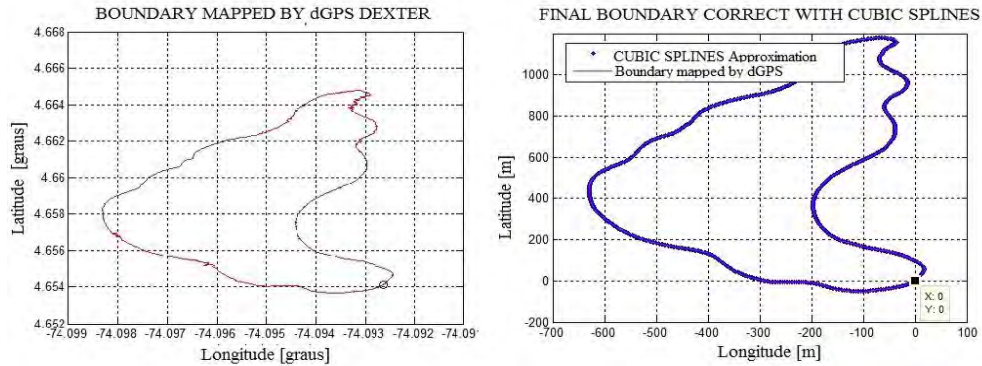

Figure 3. Measured data originally recorded on computer dGPS (left) and contour approximation corrected with cubic splines; made to local coordinates in meters (right) once plotted on the application programmed initial point at the origin.

Fig. 4 shows the three different types of edges that can be processed in the application programmed in Matlab. From it will be getting three sources: a matrix of distribution points throughout the area, an array of plants planted distribution, subtracting the lane width transverse and a dot matrix position control of vehicle for metering stations in nine plants. This is the input for the trajectory generation system.

2.3 Paths Generation system

Each point of the cultivation is considered as an object with information stored in a database including soil composition, and position coordinates amounts of fertilizer required and applied. The system starts by reading the position coordinates of the current point and the final point, the algorithm applies A-star (A *) paths generation, to set the shortest path to cover on the vehicle between two points. According to these characteristics, it was programmed in JAVA on computer application, to simulate the movement of the robot on stage. The obstacles can be placed with a computer mouse, at any point of the simulation scenario.
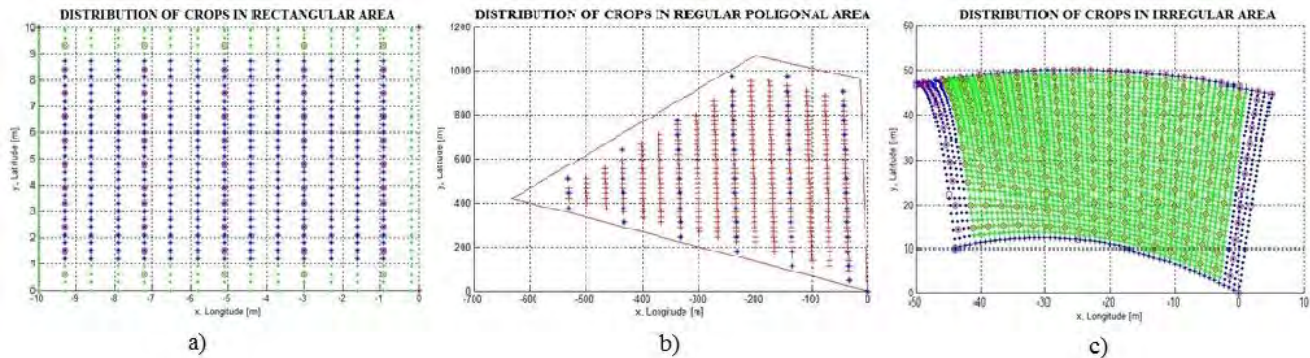
Figure 4. Distribution of growing points and control points of the vehicle position within the mapped area, for three different contours: a) simple rectangular area, b) regular polygonal area, c) irregular polygonal area. All cases correspond to different areas and different distances between plants and between rows of crops.

In Figure 5, is a snapshot of computer that displays the simulation area on the left side of the window, with the docking station (home) in the upper left of green color. At the bottom left is the simulation area, with rows of brown culture, positioning points in red and the obstacle represented by the red cube. With the Orange vehicle, shown, the direction of each point reached. In the blue box are highlighted remote communication port and buttons used on and off. On the right side of the window is the transmission area for information of simulation conditions. The red box shows the current position, the home station, and the coordinates of the requested target and algorithm selection tab to use. In the green box shows: at the top, the point sequence to follow path (gray) obtained by applying the algorithm, and at bottom (orange background), the points achieved when the vehicle moves along simulation or application notices new path of travel. In the orange box shows: simulation conditions and positions, history and type of communication to send the data.
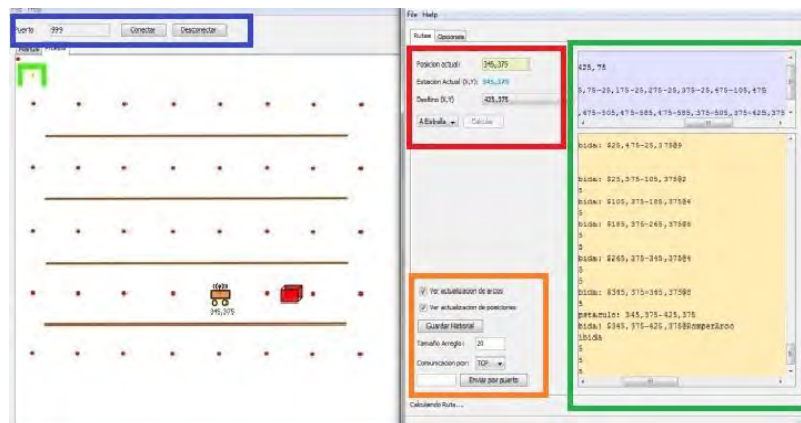

Figure 5. Area simulation paths (left) and data transfer area (right) in the computer simulation window.

The simulation capabilities of the application, were tested by measuring the consumption of computing resources according to the processing time: first, was timed loading and storing data for all points of a hectare (47619 points) following the distribution of the cultivation and percentage of computer resource consumption. Then was tested the influence of positioning accuracy between 0 and 25 cm radial error around each path point. Finally, tests were carried out with three different algorithms (Dijkstra, Floyd and A *), with and without obstacles, to evaluate the performance of the whole system and of them was selected the A * algorithm for the final application. Once applied the algorithm A*, is determined the sequence of points that make up the travel path to follow to get from the current point to the target point, which should be the dosage of fertilizers. That path is sent from computer where it is developed the data processing, via a wireless communication network type Zig Bee.

2.4 Wireless Communication Network Zig-bee.

Were selected for communication cards Xbee pro s2b of 1600 m range in line of sight by manufacturer, because of its ease of setup and use, along with its compatibility with many hardware controllers. In this case, it was used a controller, and was tested by applying independent subsystems NXT using a vehicle on a reduced scale, besides low NXT memory capacity. As shown in (Fig. 6). The program was developed in Labview for connection and disconnection of the cards, connecting with the motion control application, to communicate with the remote computer through VISA ports.

Communication was tested to see transmission efficiency: initially between two computers with X-CTU software supplied by the dealer of the cards. With it, they were tested in closed environment within a building and in the open field. Finally, with the Labview application were tested for starting and stopping the motor of vehicle in the open field, measuring the effective distance communication and control.
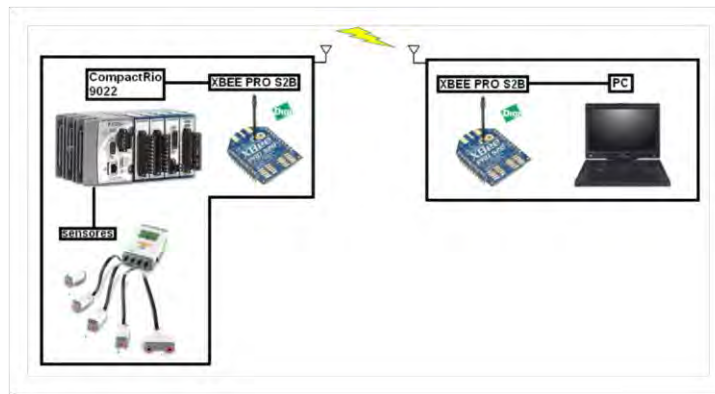

Figure 6. General structure of Zig-Bee wireless communication between controllers on board of vehicle and the remote host computer.

2.5 Storage system and data adquisition

Entire system is centralized in a database compatible with the controllers, the control system and the dosage system with communication Xbee to deliver all the information related to the different system variables such as position, dosing and control.

2.6 Structural design of vehicle and motion control system.

The structural design of the vehicle was made for a load of 500 kg with the dosing system aboard calculating the autonomy to one hectare of crop. That design was made using finite element in commercial aluminum, which is a portion of the main frame in Fig 7.
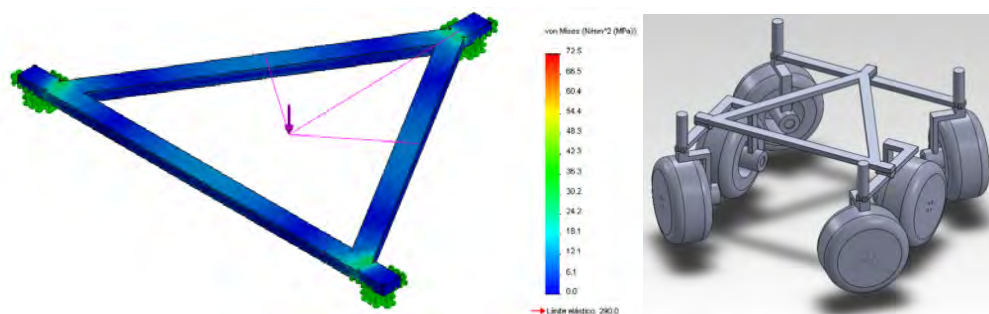

Figure 7. Main structural part example designed by finite element analysis on computer, for vehicle components (left) and three-dimensional model of vehicle on computer software CAD (right).

It was a dynamic simulation of vehicle behavior within the crop, in ANYKODE software to see a virtual behavior thereof; corrected and uncorrected positioning. Fig. 8 shows crop modeling composed of 7 rows each of 12 floors, which performs the simulation of the control algorithm, for positioning vehicle with obstacle avoidance and subsequent dosing.
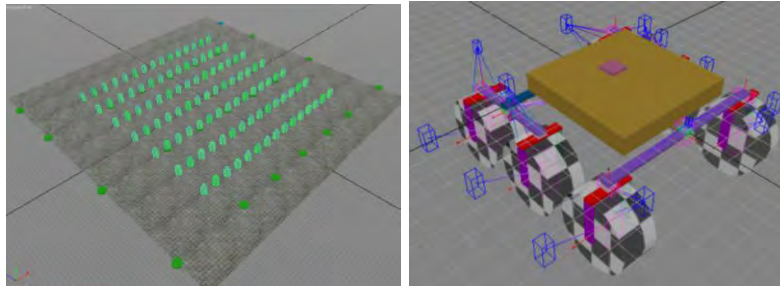

Figure 8. Culture modeling in Blender and imported after in Anikode software (left) and final vehicle geometry modeling in software with restrictions (right).

A prototype robot, was manufactured on 1:3 scale model in metallic structural aluminum profiles, using small sensors and low-cost, integrated NXT controller.

The motion control system and the generation toolpaths system were tested using a two small scale vehicle built with NXT controllers (one in Uberlandia, Brazil and one in Bogotá, Colombia), simulating the crop rows in a limited area, to test the algorithms. Fig. 9 shows an example of applying the algorithm A* on the track of Brazil with camera-based positioning NXT Cam-v3 and Fig. 10 shows an application example in Colombia, using electromagnetic sensor based on the coordinate system X, Y.
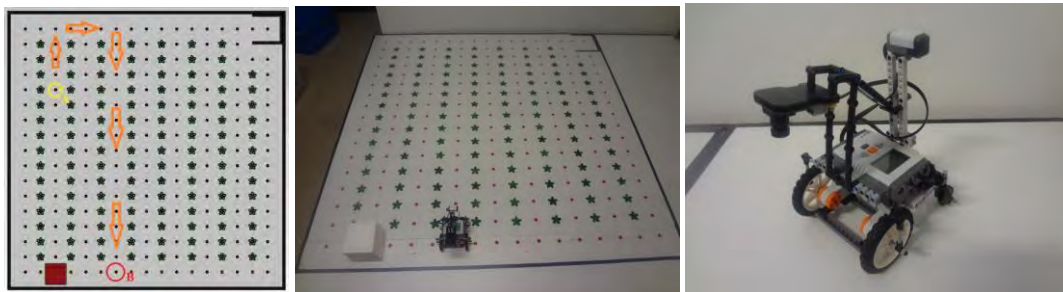

Figure 9. The Validation of A* algorithm on the runway in Brazil, with camera-based positioning and an electromagnetic sensor for NXT (Martín c *et.al., 2012*).
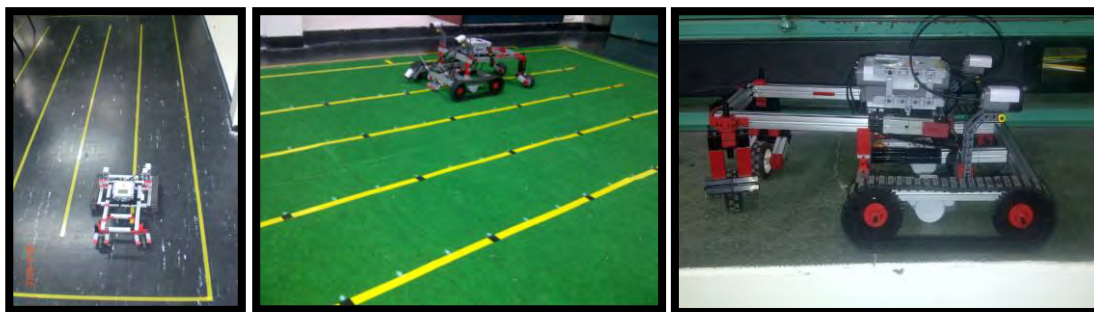

Figure 10. Validation in Colombia of positioning system using electromagnetic sensor based on the coordinate system X, Y (Martín d, 2012).

3. RESULTS

3.1 GPS measurement system.

Both GPS: dGPS sub metric and digital, measure give a good definition of shape, having some problems with satellite signal reception, the Geo Explorer 3, showed more difficulties especially in high precision. It became necessary to take the data with average accuracy and precision specifically in sunny days. It also has shown sensitivity to the present of trees and dense tall vegetation, the Geo Explorer 3 showed less precision. The Dexter dGPS requires about 5 minutes for stabilization before it takes a good measurement and has two advantages: lower cost and ease of recording of data files in real time.

The Geo Explorer 3 GPS gives a good precision with maximum error of 10.55 m, it was not better due to problems above related. The dGPS has similar accuracy and consistent error of 5m to 15m, with the accuracy given by the as well as presenting more facility to capture signals.

These measurements allow us to see the need to make GPS signal correction, since the spatial location of an autonomous vehicle is unacceptable at this level, because of the serious compromise between system functionality and safety of the vehicle itself. This accuracy can recommend the use of a submeter GPS type, combined with a data correction software "off-line" and support the positioning accuracy in a sensor system on board the vehicle.

3.2 Mesh generation and positioning control points.

The software application programmed in Matlab taking the "*.dat" files of GPS measurement, make a good correction and approximation of contour lines by Cubic spline approximation, changing the coordinate system to a local system, suitable for the system supported control sensor system on board the vehicle. This software generates a distribution points of crop based on the distance between rows and between plants appropriately, for different boundary geometries and for different planting densities.

3.3 Paths generation system.

The paths generation results with the three tested algorithms: Dijkstra, Floyd and A* with obstacles and unhindered showed efficiency in finding the shortest path between two points, including the generation of a new complementary route once found unexpected obstacle in the path defined initially. Fig. 11, shows examples of simulated routes especially with the A* algorithm used in the final application.

The behavior of the three algorithms are similar with small number of positions. With large amounts appropriate for crops around one hectare or more (47619 for potato) Floyd algorithm convergence was not reached. Dijkstra algorithms and A* have similar behavior but the A* achieves the result in a shorter time (66% less time), as shown in Table 1.
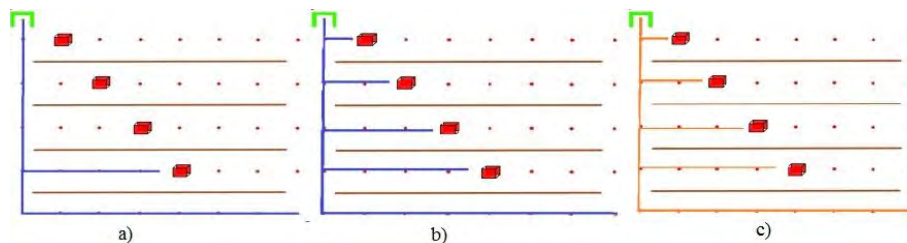

Figure 11. Simulation of paths obtained with Dijkstra algorithm (a), Floyd (b) and A* (c) in the application programmed in JAVA (Martín b *et.al.,* 2012).

Tests were carried out simulating the positioning accuracy by applying a random function that changes the actual position of the robot generating an error between 0 and 25 cm around each point. The error rate was calculated in comparison to error or ideally zero. The aim was to measure the time to reach the point according to the magnitude of the error. Table 2 shows the average of five measurements of the delay time according radial positioning error. Moreover, the time adds up to an error greater than 10 cm. That is, between 0 and 10 cm positioning error, the delay time to find the searched point involves only about 7 additional seconds maximum, while between 10 and 25 cm positioning error, means delays between 8 and 40 seconds

that become appreciable error at each point. We can see that the acceptable error can't be greater than 10 cm in practice to correct this error by given precision sensor positioning for a sufficiently reliable.

Table 1. Working time comparison of algorithms to 47619 points on a hectare of land.

PARAMETER	DIJKSTRA	A*	FLOYD
CPU use (%)	26	26	98
Memory (Mb)	970	949	977
Time (s)	75	50	--

Table 2. Simulation positioning accuracy on position radial error.

ERROR (cm)	DIJKSTRA (s)	Efficiency (%)	FLOYD (s)	Efficiency (%)	A* (s)	Efficiency (%)
0	27,56	100	27,51	100	27,44	100
5	27,93	98,67	27,88	98,67	27,83	98,59
10	35,36	77,94	33,75	81,51	34,48	79,58
15	51,8	53,20	44,47	61,86	38,23	71,77
20	52,28	52,71	55,46	49,60	50,23	54,62
25	73,85	37,31	79,37	34,66	77,89	35,22

3.4 Wireless communication system Zig-bee

The optimal communication require not any information, and according to evidence in closed environment, information is beginning to the be loss when the wireless modules are spaced about 70 meters, where the material of the walls, the ceiling and various elements ,generate interference with the communication signal and the efficiency falls rapidly to about 50%.

The wireless modules work much better in open field, in a crop of about one hectare minimum and occasional presence of obstacles in the communication space. It was noted that separating the modules around 140 meters, have no significant losses of information with an efficiency of around 96%. It can be said that there is a high reliability for stable communication between the remote station and agricultural vehicle project.

Additionally, communication tests were developed to start and stop the motor vehicle for command NXT remote controller using the Xbee cards for maximum distance of the motor vehicle going from 600 to 620 meters in straight line.

3.5 Storage system and data adquisition

They were programmed in Labview communication applications, reading and sending data acquisition and storage database, with minimum system variables, along with the composition and dosage data, in order to start a first baseman geographic information available for this type of crop.

The two systems to send and receive data handling RS232 port, both the controller and the remote station computer and there is no need to implement any kind of converter for coupling and good performance. The strategy of storing and processing in remote computer facilitates and simplifies the network sending information to the minimum necessary.

3.6 Structural design of vehicle and motion control system.

The design of the vehicle and its dynamic behavior simulation showed the feasibility of operation within the area of culture, without damaging the plants by wrong path tracking, which shows the viability of extrapolated to use in the field, some conventional algorithms use mobile and industrial robotics, for otherwise autonomous vehicles and other real environments.

For testing at hard floor and carpet made in Colombia, was establishment of error for about twenty (20) points of the crop, in order to validate the motion control system. To do this, five samples for each dosing point, and then the average was obtained for each of them. With the average was obtained the total for each point on five samples. In addition to this, the results of total error showed the maximum error to 0.059 m of distance.

With validation testing in Brazil, was applied a code that, knowing the path of robot should go on stage, and their positions and initial and final orientations, making the robot walk few markers are necessary and follow the many curves designated for the robot to reach the destination on stage. Thus, for actual application, is represented the "layout" of the cultivation, the point of departure and arrival and the presence of obstacles. With this information it calculates the route that the robot should follow. Was tested in practice the operation of the A* algorithm to generate functional paths of application based on the camera system.

4. CONCLUSIONS

After analyzing the data from GPS measurements with three different GPS is possible to conclude that the best equipment for measuring crop limits applicable to small and medium-sized crops pilot of a hectare or more, is a sub meter GPS with capacity to generate data files for streaming and preferably, with the possibility of digital data correction (DGPS) without specifying the corrective service data real-time kinematic (RTK) for the high cost and equipment required. Failing can be taken as a starting point a geographical information system or map databases reliable of National Geographic Institute.

The measurements showed that the sub-meter accuracy GPS data can be programmed into an application for medium and small crop measuring the limits on automatic mapping. However, showed that the distances being so small, the GPS does not have sufficient accuracy for positioning within the crop. This suggests applying other positioning systems and positioning the robot measurement within the crop. For that it is possible to rely on measurement and feedback with in-vehicle sensor system with a much lower cost.

The application programmed in Matlab software behaves correctly from file mapped by GPS data to tailor the outline to another measurement system not dependent on GPS. The mesh generation of distribution crops according to the characteristics based on the distance between rows and plant spacing is correct and viable for different configurations, which makes it adaptable to different crops.

Automatic distribution of the crop in the area is appropriately optimized way, taking into account the distances of the sides of the regular or irregular polygon, to distribute the plants with better utilization of area crop. Furthermore, based on the most common ways for small crops in the country.

The algorithms tested, delivered the shortest route between two points. However, the Floyd algorithm, it fails to compute routes for lots of points being the maximum for an area of 10 m by 10 m approximately.

The A * algorithm was shown to be better than Dijkstra algorithm more time difference especially when many points. However, Dijkstra algorithm can calculate different routes at different points, from an initial position, being better for multicast paths.

For major crops can apply the algorithm A* lowering the amount of position points metering stations with multiple stop positions. That is, to multiple plants at each stop or station in this case, nine plants per station.

With the results obtained in the present work, it becomes clear that it is perfectly possible to build a robot to navigate properly and autonomously in a small crop without damaging the plants is potato or any other crop, to apply fertilizer, irrigation, collection or any other activity that may play an autonomous mobile robot.

The communication with Zig-bee system proved to be flexible, efficient and sufficient for agricultural application of small or medium size, easily configurable allowing network should extend the field of network coverage with low implementation cost.

The developed monitoring screen allows real-time information system behavior, so that it's possible to make immediate decisions in the presence of possible malfunctions.

The system designed to acquire signals using commercial technology devices and lower-cost technologies available for such large-scale applications, with software deployment and storage management, allowed to obtain reliable information on application, combining the interaction of the vehicle with the crop, and the positioning environment.

Again, versatility is the use of computer technology and simulation design for the preliminary validation of system behavior before building functional prototypes, reducing testing costs substantially.

The offset error of the robot is 0.02 meters perform each transfer, giving reliability and precision that each robot perform shift at each point of the crop.

By means of tests performed on a smooth and one rough terrain, it was concluded that the robot has good performance on both surfaces, the only downside was obtained, is that the robot smooth slide when making the shift to 90 ° due to method of reverse rotation of motors, clarifying that rotates about its geometric center perfectly as it was raised. This was solved by changing the six-wheel design for displacement.

The tests confirm that not only allowed from sensor system can be carried out the positioning of the robot within the crop, by vision system from the camera can also be achieved. Failing that, can be used a combined system between vision and sensor and get possibly a more accurate system.

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