Fertilizer Dosage Vehicle via Global Positioning System with technology for small productions

Vehículo para Dosificación de Fertilizantes vía GPS con Tecnología para pequeñas producciones

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***Abstract*—An autonomous system was developed, able to move within a culture with accurately and efficiently; being practical and economically feasible to dosing fertilizers in small crops, which make up of the most area for agricultural production in Colombia. This system *use of culture* limits by GPS coordinates *for* distribution and generation t*he* positioning points on one hectare pilot. The GPS coordinates are saved on a file and used to generate points of path planning computer application by interpolation with cubic polynomials. Using this methodology, the crop distribution within the area is established and the automatic positioning points within the crop are determined. From these points, the paths are generated to be followed by the vehicle to travel between two points without damaging the crop; supported in a wireless communication between the computer and the vehicle. The result is based on a vehicle capable of traveling through the crop rows to dose liquid fertilizers of nitrogen, potassium and phosphorus in a controlled manner, with error less than 4% by volume; following the paths determined with an error less than 10 cm, from sensors located on board the vehicle with remote control system.**

Keywords—Autonomous vehicle, GPS, dosing fertilizers, path planning, precision farming.

I. Introduction

The growing demand for food worldwide, implies a significant increase in agricultural production. Therefore, increasing the efficiency of seeding, harvesting and production per square meter is required. Now has been develop an automation of farming, due to the shortage of skilled labor and lack of tech production; specially in Colombia, where agricultural production is a high percentage of family-level, manually and in small rural production areas.

In agriculture today, seeks to obtain the maximum benefit with minimum cost, better use of resources and intervening soil and the environment as little as possible. For this, the application of new technologies for planning, production and automatic crop management is required. That is called today as "precision agriculture" [1] and allows maximum potential soil per hectare using less fertilizer, less degradation and higher performance; using automatic equipment with sensors [2], automatic detection [3], global positioning systems (GPS) [4] and geographic information systems (GIS) [5] in robotic applications for sowing [6], dosage and/or fertilizer application, crop harvesting, irrigation and weeding [7] among others. These systems are based on physical, chemical and geographical conditions; with paths optimized on computer [8]; for better use of soils; higher productivity and variable dosing fertilizers in a localized manner. Today, robotics applications are focuses on the development of vehicles [9] and applied on the field systems. Given this need, there was developed an autonomous system that moves in a crop by applying localized fertilizer. The system based on the limits of crops by GPS, making the distribution crops in the mapped area, generating the control points for robot positioning. With this information, the independent paths are generated, to perform localized fertilizer dosage on the crop. Each one of developed systems is summarized and the results of behavior are established with precision positioning and dosing NPK fertilizers variable rate achieved.

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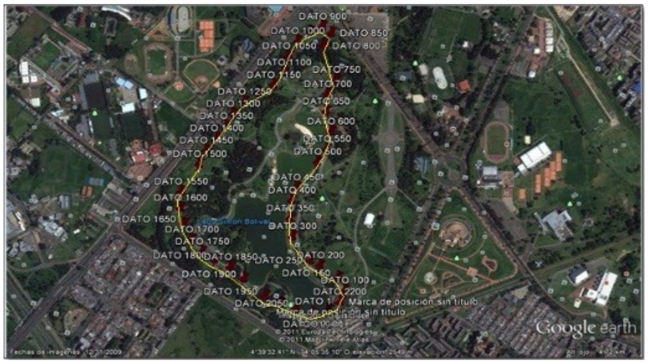
II. Developed System

To develop the vehicle, it was determined the conditions of a pilot crop; to set specific conditions [10]. The crop was selected for its size, characteristics, quantity of production, demand and accessibility from Bogota city; with organic fertilizers of nitrogen (N), phosphorus (P) and potassium (K). For these conditions and crop characteristics were developed the component systems.

A. Positioning System with GPS coordinates

A viable application for small and medium-sized crops depends on the GPS system; it´s required an equipment of high precision of high cost, including the permanent data acquisition service. For this, the alternative is make a mapping limits with GPS and then computing the distribution crop and control points for robot movement into the crop, follows the paths calculated with computer program. An example of GPS measured contours is shown in Fig. 1 on the Simon Bolivar Park in Bogota city.

Fig. 1. Representation of GPS data limits collected in the Simon Bolivar Park in Bogota city, Colombia (Google Earth Version 6.0.1.2032 - beta).



B. Mesh generation and positioning control points.

Based on GPS data files, an application in Matlab® software that converts data GPS to metric distances with a local coordinate system was programmed. To improve the accuracy of contours, became Spline approximation with cubic polynomials; to obtain a smooth contour of crop limits. This methodology was developed based on the methodology for three dimensional contours reading of Rangel [11]; to increase the accuracy of data GPS and reduce errors for contours; which is based on the first four points to interpolate intermediate points, which serve as the basis for estimating the next point.

Known the start and end points of the curve, a parametric curve given by three cubic polynomials whose vector equation can be written as follows:

$$\boldsymbol{P}(u) = \boldsymbol{a}_3 \cdot u^3 + \boldsymbol{a}_2 \cdot u^2 + \boldsymbol{a}_1 \cdot u + \boldsymbol{a}_0 \quad (1)$$

Where: P(u) is the position vector of any point on the curve and a_0, a_1, a_2, a_3, are the equivalent vectors of scalar coefficients. Using the start and end points p(0) and p(1) and tangent to estimate the polynomials coefficients, it´s obtained *the geometric form of polynomial equation,* as follows:

$$\boldsymbol{P} = F_1 \cdot \boldsymbol{p}_0 + F_2 \cdot \boldsymbol{p}_1 + F_3 \cdot \boldsymbol{p}_0' + F_4 \cdot \boldsymbol{p}_1' \quad (2)$$

Where: p_1, $p_{0'}$ and $p_{1'}$ are called geometric coefficients and terms F_1, F_2, F_3 and F_4 are *blending functions*. Depending on the control type (or number points on the curve), the F parameters must be set from the point u. In CAD systems and vision systems, for computational ease, the parametric curves of Bezier or spline types are used [12].

In this methodology, it was used a polynomial spline type with four control points and blending functions re-parameterized in a specific range, as follows:

$$F_1 = \frac{1}{6}(-u^3 + 3 \cdot u^2 + 3 \cdot u + 1)$$

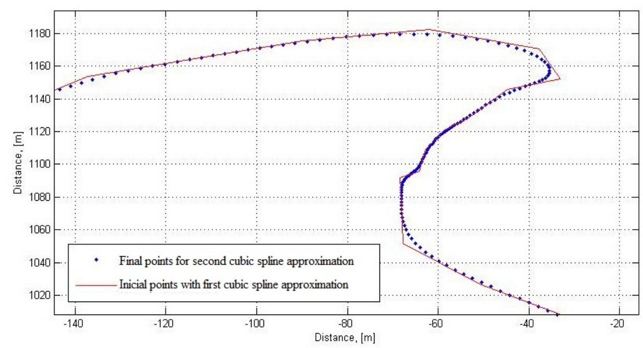
$$F_2 = \frac{1}{6}(3 \cdot u^3 - 6 \cdot u^2 + 3 \cdot u) \quad (3)$$

$$F_3 = \frac{1}{6}(-3 \cdot u^3 + 3 \cdot u)$$

$$F_4 = \frac{1}{6}(u^3 + 4 \cdot u^2 + u)$$

From these equations, the contour was approximated and the results line of dots are shown in Fig 2, where the red line representing the first cubic interpolation estimated with polynomial type "Spline" values, from distance between plants; and a greater accuracy was obtained in the final contour after a second approach, it shown with blue dots.

Fig. 2. Detail of contour approach to "Spline" enhanced by second interpolation.



These data are information source to generate the crop distribution points and control positioning points of vehicle for three different contours: 1) rectangular area, shown in Fig. 3; 2) regular polygonal area, shown in Fig. 4; and 3) irregular area, shown in Fig. 5. As a result, was obtain a parent distribution points throughout the area, a distribution matrix seeded plants subtracting the transverse way and the positioning control points of vehicle; with stations for nine plants simultaneously. This data are input for the path planning system.

Fig. 3. Distribution crop points (blue) and control points (red) for positioning on rectangular area.

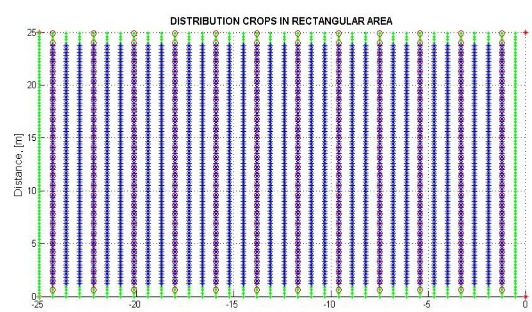


Fig. 4. Distribution crop points (red) and control points (blue) for positioning on regular polygonal area.

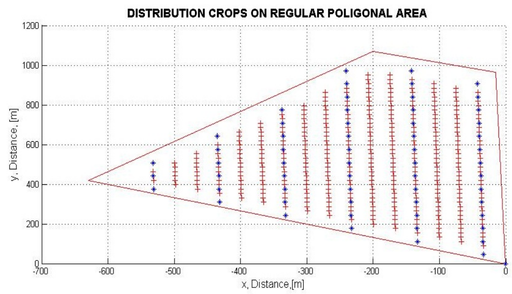
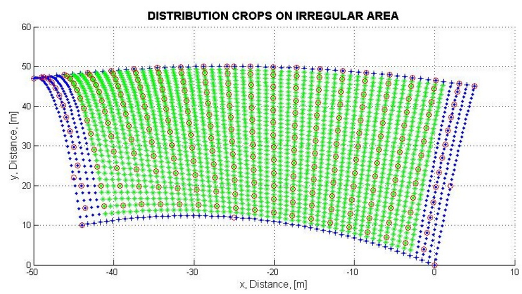


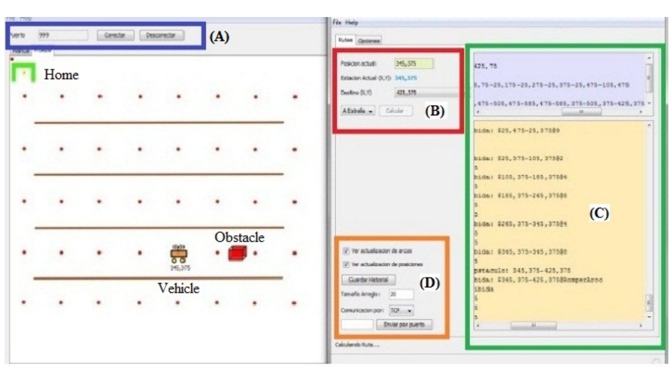
Fig. 5. Distribution crop points (green) and control points (red) for positioning on irregular area.



C. *The path planning system.*

Each point of the crop is an object with information stored in a database, including the composition of soil, positioning points and fertilizers doses required and applied. The system from the current point and the target point, applies A-star (A *) algorithm to establish the shortest way for displacement. The paths were simulated, placing obstacles in any point on simulation scenario. Fig 6, shows an image of simulation area on the left side of the window, with the docking station for recharging (home) in green, the crop rows, the orange vehicle and the red obstacle. The blue box (A), highlights the communication port and the buttons of connection and disconnection. On the right hand side, the red box (B) shows the current position, the home position, the target point and the algorithm used. The green box (C) shows the sequence points of path (gray background); the passed points and the new path obtained. The orange box (D) shows the simulation conditions, history, and communication type to send data.

Fig. 6. Paths simulation area (left) and transfer data area (right) of window on software simulation.



The simulation capability of application, was tested for one hectare (47619 plants) on selected crop, analyzing the influence in accuracy between 0 and 25 cm of radial position error.

After applying the A * algorithm, it´s given a sequence points that make up the path; to get from the current location to the destination point and make the dosage fertilizers. That path is sent from computer to vehicle through a Zig-Bee wireless network. For communication were selected Xbee pro cards to 1600 m of distance; for easiness and usage, beside the compatibility with many drivers. The transmission was tested between two computers with X-CTU software provided by the manufacturer, in both closed and open-field environment. Finally, with a Labview® application was test for starting and stopping the motor vehicle in the open field by measuring the effective communication distance and control.

Fig. 7 shows an example where free nodes are the red dots, the unreachable nodes are the plants and the obstacle is a red square. The starting point is in yellow circle (A) and end point in the red circle (B) from which was computed the path of least distance, shown with orange arrows.

D. *Dosing fertilizers system*

An application example was developed for dosing fertilizers for nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) variable rate; for controlled dosage of nine different plants per station, depending of distribution control points obtained in Matlab® application.

To validate the system, a prototype was built at 1:3 scale shown in Fig 8 with independent dosing by solenoid valves and sprinklers. Each sprinkler is a dosing point on a plant, with a pre-set dose computed from database.

Fig. 7. Example of computing paths using the A* algorithm.

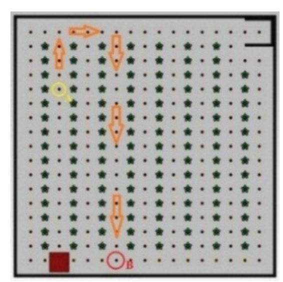
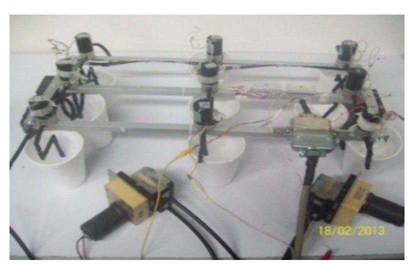


Fig. 8. General diagram of fertilizer system in 1:3 scale.



The dosing times for commercial fertilizers are computed from one hectare of crop recommendations, together with the concentrations of fertilizers and application conditions from database can be supplemented by adding new fertilizers.

When the established doses are typed, the software made the calculus of the required volume per hectare and estimated flow for each one specific commercial product selected from database.

This application was tested with several commercial products, and integrated monitoring application in Labview®; to validate the dose in real time with the prototype shown in Fig. 8. Fig. 9 shows the main interface of the application developed. The amounts were measured with glass cylinder of 50 ml or 100 ml at each point and the volume dosage error was computed.

E. Structural design and control system

The vehicle structural design was made to support 500 kg while the dosing system on board for one hectare of crop, applying finite element method, was made in commercial aluminum, as shown in Fig 10. A dynamic vehicle simulation was made within the crop on ANYKODE software; for behavior with correction and without correction of positioning error. Fig. 11 shows the crop modeling software with 7 rows of 12 plants, for positioning the vehicle, avoidance obstacles and dosing fertilizers.

The control motion, path planning systems and prototypes were tested using a 1:3 scale model with NXT controller; clues for functional validation in laboratory (in Uberlândia, Brazil and Bogotá, Colombia). An example of application the A* algorithm is shown in Fig. 12, using electromagnetic sensor with X, Y coordinates and a camera-based positioning with NXT Cam-v3 and an electromagnetic sensor.

Fig. 9. Labview dosage interface for nitrogen, potassium and phosphorus liquid fertilizers.

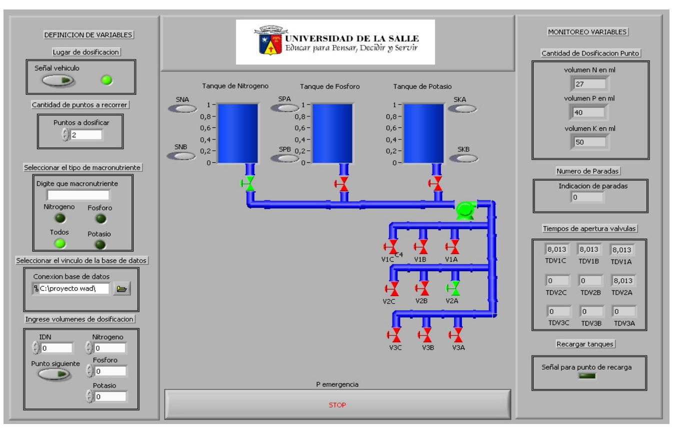


Fig. 10. Structural design (left) and three-dimensional model of vehicle (right).

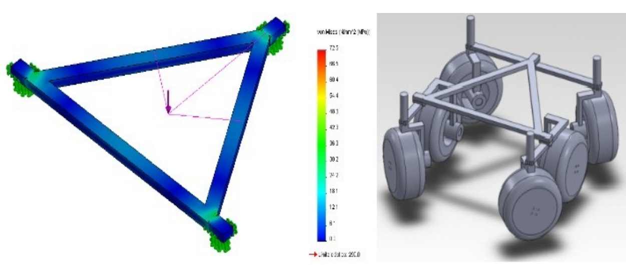
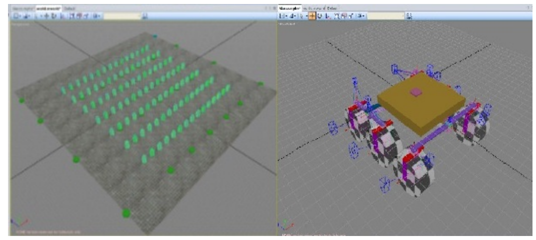


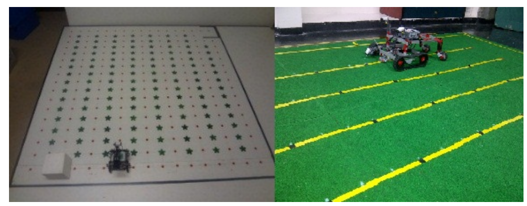
Fig. 11. Terrain modeling for crop simulation (left) and final geometry with constraints (right) on dynamic simulation.



III. Results

The GPS contour measurement has good definition of shape, but it has some problems receiving satellite signals with cloudy sky, trees and obstacles presences. However, a dGPS with generation data file, can make good readings easily and at very low cost, with recording data GPS in real time.

Fig. 12. Validation of the A * algorithm in Brazil, with NXT camera (left) and sensors included in Colombia (right).

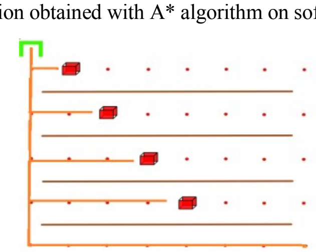


The standard error of this equipment using GPS data free it´s from 5 to 15 m with an average of 10.55 m obtained. For this reason it is necessary to use the correction data by triangulation, for spatial localization of an autonomous vehicle. This error is unacceptable and could severely compromise the system functionality and integrity of vehicle. Furthermore, the accuracy of contour, depends importantly of the precision data GPS into the crop.

The application programmed in Matlab with GPS input data, makes a good correction and contour approximation by cubic spline approximation, changing the global coordinate system by one local to the control with sensors on board vehicle. This software generates a distribution points based on the distance between rows and between plants, for different geometries and boundary densities for different crops distribution.

The paths generated using the A* algorithm with and without obstacles, is efficient in finding the shortest path between two points, including the request for a new route to an unexpected obstacle as in Fig. 13.

Fig. 13. Paths simulation obtained with A* algorithm on software.



In tests it using a random function to generate positioning error between 0 and 25 cm from the point sought and taking the ideal error like null, it was found that the maximum acceptable error is 10 cm, with a maximum time of 7 s and can be corrected with positioning sensor.

There is a significant loss indoor communication when the modules are apart of 70 m minimum, due to interference of the walls and objects present; rapidly decreasing communication efficiency up to about 50% of distance.

In the open space, on a crop of one hectare approximately and with occasional presence of obstacles and / or trees, the x-bee cards can be separated about 140 m without significant loss of communication with an efficiency of 96% approximately. In tests of the motor using the cards in open space, an effective operation was achieved up to 600 m away, which makes only two cards (transmitter and receiver) required for one hectare of crop.

The dynamic simulation showed the feasibility for operating within the crop without damaging the plants and confirmed the usefulness of path generation algorithms in applications on open spaces and real environments.

The positioning system with a low costs camera, was appropriate for generation and tracking paths using the A * algorithm. In tests of hard and soft floor on 20 crop points with average minimum five repetitions, the results showed a flat maximum error of 0.059 m away.

IV. CONCLUSIONS

The most appropriate proceeding for measure the limits of small and medium crop equipment, is a sub-meter GPS data file generation, transmission and preferably in real time, with the possibility of digital data correction (DGPS).

To the limits it is possible for integrate the database or maps of national geographic institute and a GIS system.

The application developed in Matlab® software behaves correctly from data file mapped by GPS, and can be adapt the outline to another system of local and independent GPS measurement.

The mesh generation crop distribution, based on the distance between rows and between plants, is correct and viable for different geometries of common crops in Colombia.

The A * algorithm is fast and suitable to determine the paths of travel and can be optimized in older crops, forming stations with multiple and simultaneous dosing plants per station.

It´s possible to build a robot for navigation autonomously in a small crop, without damaging the crop, to apply fertilizer, irrigation, harvesting or any other activity that may play related to the crop.

The configuration and Zig-bee communication system is flexible, efficient and suitable for agricultural application of small or medium size, allowing an easily reconfigurable network to expand the area of coverage at low cost.

The data computed for commercial fertilizers on database maybe introduced for new fertilizers, allowing to see a great potential for application on commercial products.

The prototype on scale 1:3 allowed a correct and reliable dosage to validate the operation times and volumes on actual fertilizers, according to computed values from database.

The dosing system is a viable application developed for small to medium crops with maximum error of 3.67% by volume.

The offset error of the robot is between 0.02 and 0.06 m above the point sought, giving reliability and precision movement within the crop, according to laboratory testing scaled.

The positioning of the robot can be obtained by vision systems or a combination of vision and sensor system on small or medium crops; for more accurate system possibly.

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