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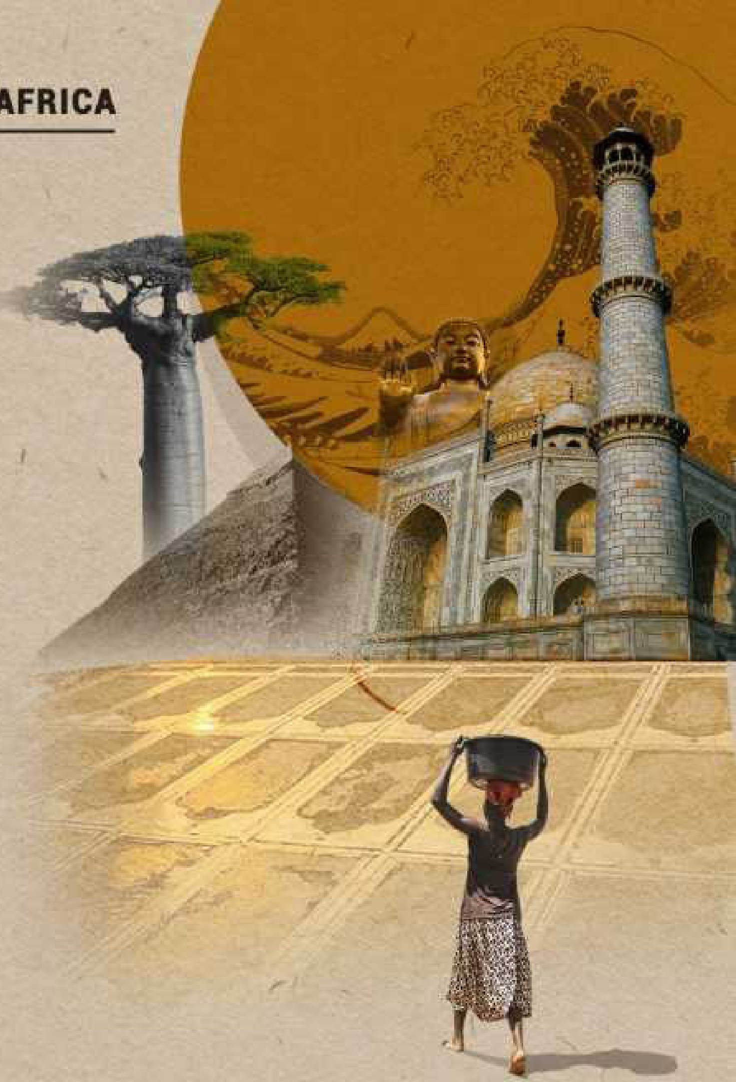

"WORKING *PAPER 7*"

Development of a farm robot (Voltan)

Noé Velázquez

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Development of a farm robot (Voltan)

Noé Velázquez

Resumen

A lo largo del último siglo, la agricultura ha pasado de ser una industria con una gran cantidad de mano de obra a otra que utiliza sistemas de producción mecanizados y de enorme potencia. La introducción de la tecnología robótica en la agricultura podría suponer un nuevo paso hacia la productividad laboral. Al imitar las habilidades humanas o ampliarlas, los robots superan las limitaciones humanas críticas, incluida la capacidad de operar en entornos agrícolas difíciles.

En este contexto, en 2014 se inició el desarrollo del primer robot agrícola en México ("Voltan") en la Universidad Autónoma Chapingo. El objetivo de la investigación fue desarrollar un vehículo autónomo multitarea para trabajos agrícolas. Como resultado de este desarrollo, se creó un novedoso sistema de suspensión. Además, se logró la navegación autónoma entre las hileras de cultivo mediante la visión por computadora, lo cual permite la monitorización de los cultivos, la aplicación de fertilizantes y, en general, el control de plagas y enfermedades.

Abstract

Over the last century, agriculture has evolved from a labor-intensive industry to one that uses mechanized, high-powered production systems. The introduction of robotic technology in agriculture could be a new step towards labor productivity. By mimicking or extending human skills, robots overcome critical human limitations, including the ability to operate in harsh agricultural environments. In this context, in 2014 the development of the first agricultural robot in Mexico ("Voltan") began at Chapingo Autonomous University. The research's objective was to develop an autonomous multitasking vehicle for agricultural work. As a result of this development, a novel suspension system was created. In addition, autonomous navigation between crop rows was achieved through computer vision, allowing crop monitoring, fertilizer application and, in general, pest and disease control.

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INTRODUCTION

Over the last century, agriculture has been transformed from a labor-intensive industry towards one using mechanization and power-intensive production systems (Marinoudi *et al*., 2019). Agricultural productivity has significantly increased throughout the years through intensification, mechanization, and automation. Most of the significant developments in agriculture mechanization occurred during the 20th century. Tractors, combines, and other farm machinery were continuously refined during the second half of the 20th century to be more efficient, productive, and user-friendly (Edan *et al*., 2009). Computer-based sensors and actuators such as global positioning systems, machine vision, and laser-based sensors have been progressively incorporated into mobile robots with the aim of configuring autonomous systems capable of shifting operator activities in agricultural tasks (Emmi *et al*., 2014). In agriculture, small robots can be used for many field tasks such as collection of soil or plant samples and detection of weed, insect or plant stress. When equipped with a larger energy source and appropriate actuators, they can also be used for localized treatments such as spot-spraying of chemicals or mechanical in row weeding (Edan *et al*., 2009). Robotics and Autonomous Systems (RAS) are set to transform many global industries. These technologies will have the greatest impact on large sectors of the economy with relatively low productivity such as Agri-Food. However, research is needed into robotic platforms that can operate close to the crop (either on the ground or at elevation) and advanced manipulation, especially with interactive or tactile properties. One advantage of modern robotics is their ability to be built using low-cost, lightweight and smart components (Duckett *et al*., 2018). Smart farming (SF), based on the incorporation of information and communication technologies into machinery, equipment, and sensors in agricultural production systems, allows a large volume of data and information to be generated with progressive insertion of automation into the process (Pivoto *et al*., 2018)

The introduction of robotic technology into agriculture could create a new step change towards labor productivity. By imitating human skills or expanding them, robots overcome critical human constraints; including an ability to operate in difficult agricultural environments (Marinoudi *et al*., 2019). Skid-steered robots will play an important role in agricultural robotics due to their flexibility and simple construction (Fernández *et al*., 2018).

In Mexico's case, the process of agricultural mechanization during the first half of the twentieth century, the acquisition of tractors and plows was inscribed, with great limitations, in the productive orientation developed by governments. However, by the middle of this century, with the implementation of the green revolution, the purchase of tractors began to occur massively and increasingly, which marks the beginning of a new technological culture. In Mexico most tractors range between 60 and 80 hp. In terms of productive efficiency, the appropriate power/surface ratio is 1hp·ha-1. Therefore these tractors have a coverage potential for agricultural work of approximately 80ha (Palacios and Ocampo, 2012). However, the dynamics of the use of the tractor causes its power to be underutilized in most Mexican plots where 91.1% of Mexico's producers have average areas equal to or less than 7.65 ha (Palacios and Ocampo, 2012).

In this context, in 2014 the development of the first agricultural robot in Mexico started at Chapingo Autonomous University. The research's objective was to develop a multi-tasking autonomous vehicle for agricultural tasks.

Materials and methods

The methodology for mechanical design proposed by Budynas and Keith (2015) was applied for this agricultural robot's development.

At the initial stage, a review was made regarding automation in agriculture to find out what restrictions researchers have faced developing this type of technology. It was also necessary to apply robotics techniques, which relates to the desire to synthesize some aspects of human function using mechanisms, sensors, actuators, and computers.

Regarding the motion type, robotic tasks call for a range of steering activity: one extreme is highway driving with negligible turning for hundreds of kilometers, another is forklift handling which calls for agile turning. Skid steering can be compact, light, require few parts, and exhibit agility from point turning to line driving using only the motions, components, and swept volume needed for straight driving (Shamah, 1999).

Skid-steering mobile robots are widely used because of their simple mechanism and robustness. Steering in this way is based on controlling the relative velocities of the left and right-side drives. The robot turning requires slippage of the wheels for wheeled vehicles. (Wang et al., 2015). Due to all advantages and simplicity, the skid steering configuration was chosen. In addition, the following minimum requirements were proposed for the prototype: It must be economical, the maximum operating velocity was set to 6km/h, it should be capable of operating with a load of 60kg, robust and with enough energy independence.

Mechanical subsystem

The main parameters for selecting motors, drivers and designing all mechanical components of the robot were maximum velocity and a maximum load. These parameters allowed for the designing of the chassis as well as the transmission drive and motion configuration.

Tires

Tires are responsible for traction development and forward movement of the vehicle. The energy consumed in the forward movement of tires mainly depends upon the type of traction device, terrain condition and normal load on the vehicle. The traction energy efficiency of the tires on any surface depends on the dynamic vertical load, the size and shape of the area of contact with the ground and the surface characteristics (Kumar *et al*., 2019). For this robot, agricultural type tires of 25 cm diameter were selected.

Power Support Arms and transmission chain

Four arms were designed and built. The purpose of the arms is to give enough clearance to the vehicle, transmit power from the motor to the wheels and as a support for the suspension system. The arms were manufactured with aluminum.

A chain power transmission, which is a very efficient method of power transmission, was selected to transmit the mechanical power from one axle to another. The chain was fixed and two motors were used. The vehicle was designed to be 4WD. A 18 teeth, 1/2" chain pitch and chain size 40 sprocket was selected and according to the geometry of the chain transmission, a 44 links chain was chosen.

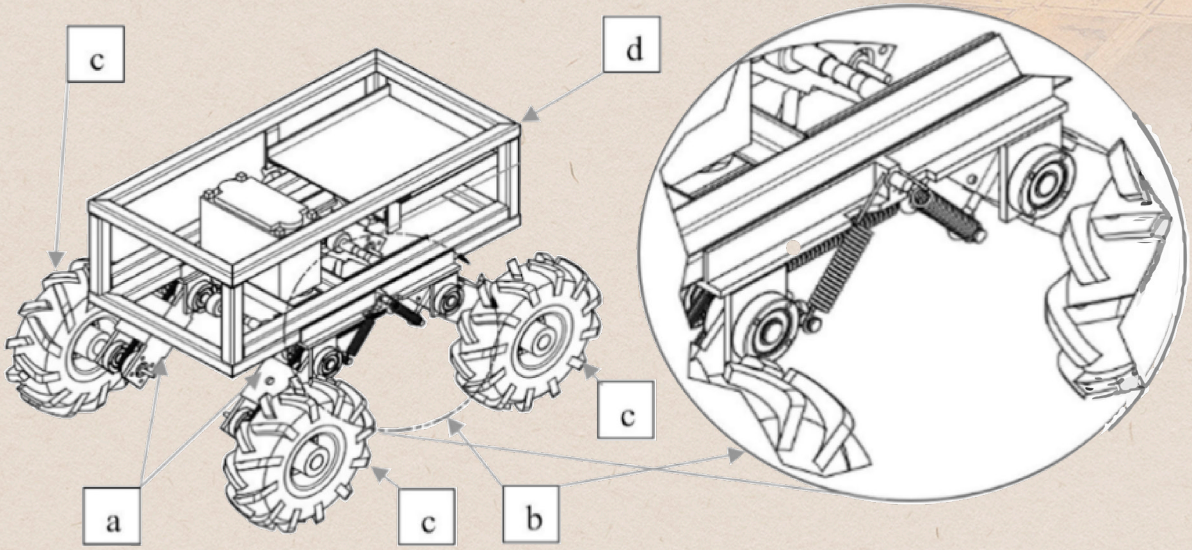
Suspension system

It is well known that ground vehicles require suspension systems in order to absorb vibrations in sudden movements and impacts from rolling over rough terrain; in such a way that suspension systems give the vehicle stability while on the go, in addition to avoid damage to the vehicle structure, misalignment of structures and most importantly to all four wheels in contact to the ground. In the process of developing this prototype a novel suspension system was created (Reyes and Velázquez, 2018).

In general, the suspension system consists of at least two coil springs that work at tension configured to dampen a side support arm that holds a rim at the bottom of the vehicle (Figure 1), where the side support arm is fixed pivoting on one side of the chassis, projected front wheel front or rear wheel for rear wheel; and where one of these coil springs is mounted diagonally and fixed at its top end in the middle section of the lower part of the vehicle chassis and fixed at its lower end at an extension of the upper end of that side support arm, in order to damp the same during vehicle movement; another of these coil springs is arranged in a horizontal position fixed at one end at the same extension of the upper end of that side support arm which lower supports its respective rim, and at the opposite end at a Lower support element in the central area of the chassis, to keep the position of said side support arm in balance as it opposes resistance to the time rotation or anti-clockwise of the same and thus allows to keep it always in the starting position.

In another modality, the coil spring that is arranged in a horizontal position is common for the two lateral support arms attached to the same side of the vehicle chassis, i.e. it is fixed at its two ends at the extension of the upper end of two attached lateral support arms which support their respective rim inferiorly, one projecting frontally and the other projecting rearly, defining a triangular arrangement of three coil springs working under tension, to maintain the position of these attached lateral support arms in balance, as it opposes resistance to the clockwise or counterclockwise rotation of these allowing them to always be maintained in the starting position. The upper end of each of these attached lateral support arms is pivotally mounted to a chassis fastener, and where at the lower end of each support arm , the front and rear wheel axles are mounted on each side of the vehicle.

Figure 1. Suspension system. a) Support arms, c) Tires and d) Chassis



Source: Reyes-Amado and Velázquez -López (2018).

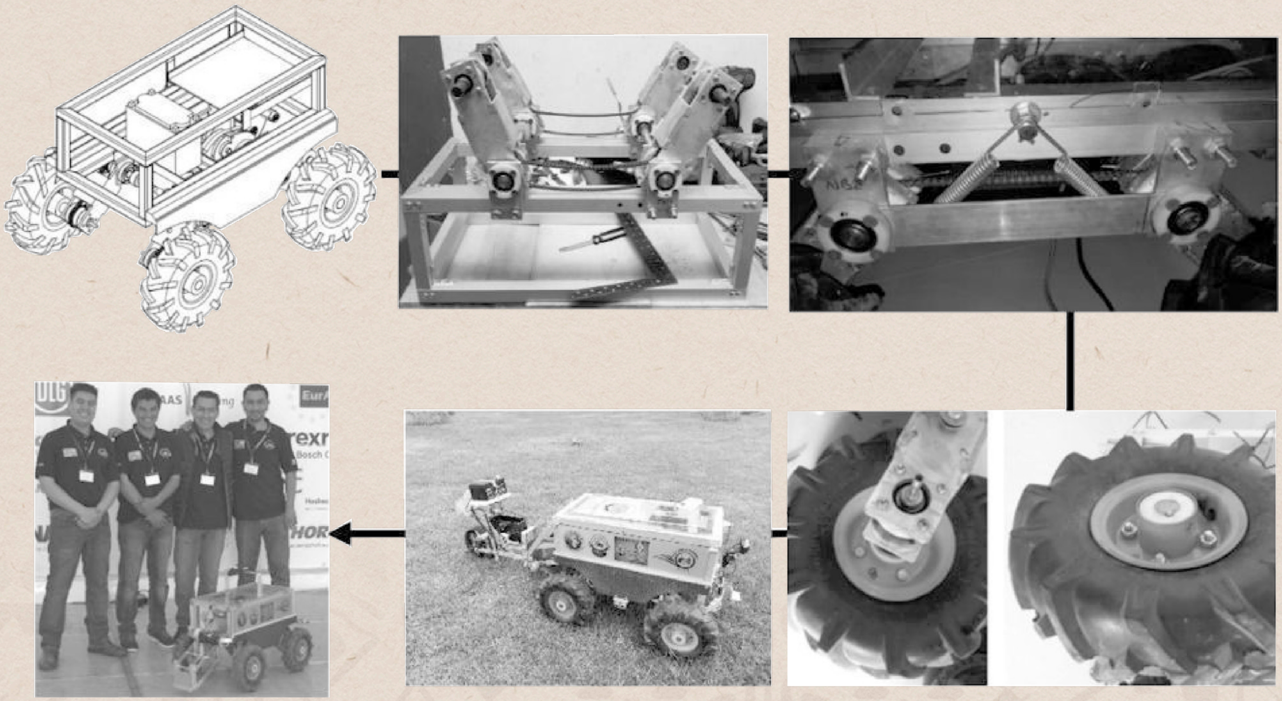
Frame (structure)

All the instrumentations and controllers were mounted into the main structure), which was built with aluminum. The frame was assembled with screws and nuts, to allow more practical disassembly in case it is required for future modifications. All the frame was covered with acrylic to protect the electronic components from dust and water.

The main features of our robot are listed below. In figure 2 the construction process is shown.

- Frame.
- Power unit.
- Electrical systems.
- Transmission systems.
- Tires.
- Attachments.

Figure 2. Robot construction process



Source: Pictures taken by the author.

ELECTRICAL SUBSYSTEM

Drivers and motors

The vehicle's power source will be the DC motor. Two aspects were considered to select it:

a) Power

To calculate the power, a maximum load of 60 kg was considered. This load considersthe weight of the vehicle as well as its implements. To calculate the power the following equation was used.

$$P = F * v \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(1)}$$

Where: P-power (W), F-Force (N), v-velocity ($m \cdot s^{-1}$)

A velocity of 4 $km \cdot h^{-1}$ (1.11 $m \cdot s^{-1}$) was considered for operation and a maximum velocity of 6 $km \cdot h^{-1}$ (1.67 $m \cdot s^{-1}$) for transportation. The force was calculated as follows:

$$F = m * g = 60\, kg * 9.81\, m * s^{-2} = 588.60\, N \ldots\ldots \mathbf{(2)}$$

Where: F-Force (N); m-mass (kg); g-gravity acceleration constant ($m \cdot s^{-2}$).

Finally, the power required is:

$$P = (588.6\, N)\left(1.111 \frac{m}{s}\right) = 653.94\, W$$

This is the minimum total power required regardless of slippery or actual traction with the ground.

b) Angular velocity (rpm)

In order to calculate the maximum rpm, the maximum speed specified for this vehicle is 6 $km \cdot h^{-1}$.

Angular velocity was calculated using equation 3.

$$v = \omega \cdot r \qquad \text{(3)}$$

Where: v-Linear velocity ($m \cdot s^{-1}$), ω-angular velocity ($rad \cdot s^{-1}$) and r-radius (m).

The diameter of the tires is 0.26 m, therefore r=0.13m. The proposed maximum speed of the robot was $v=1.67\ m \cdot s^{-1}$. From equation 3

$$\omega = v/r = 1.67\ m \cdot s^{-1} / 0.13m = 12.8231\ rad \cdot s^{-1}$$

Finally, to convert to rpm equation 4 was used.

$$\omega = \frac{\pi * n}{30} \qquad \text{(4)}$$

As a result, n was obtained:

$$n = \frac{30 * \omega}{\pi} = \frac{30 * 12.8231}{\pi} = 122.452\ rpm.$$

With this information, we proceeded to look for a motor. The selected motor characteristics are described in table 1. This motor was selected due to its convenient characteristics, such as torque, energy consumption and price.

Table 1. Motor features

Voltage	**12 V**
Angular Speed	**139 rpm**
Power	**490 W**
Current consumption	**2-70 A**
Maximum load	**59 kg**
Torque	**33.5 Nm**

Source: Own elaboration.

The current consumption is high varying from 2 A to 70 A at load stop, that is, when presented with a load with enough torque to stop the motor's rotation at its best performance, the maximum efficiency consumes a current of about 10 A.

With this information the driver IBT-3 model was selected. It is capable of speed control by PWM (pulse width modulation). The parameters considered for the selection of this component were the battery, power dissipation, and above all current intensity, according the manufacturer's information. Driver features are shown in table 2.

Table 2. Driver features

Operating Temperature	**0-70 °C**
Power dissipation	**100 W**
Type	**Drive IC**
Supply voltage	**5V-15V**
Model	**IBT-3**
Current	50 A
With isolated microcontroller PWM signal	IBT-3

Source: Own elaboration.

SENSORS

Encoder EE-SX1103

Two incremental rotary encoders with a resolution of 5000 pulses per revolution (Autonics, model EP50S8-5000-3-T-5). Pulse reading was done with an Arduino ATMega 2560 board, and an algorithm was programmed to calculate the distances traveled considering the diameter of the wheels. Accuracy in distance measurement was +0.05 mm. Both encoders were installed on the drive wheel arm and connected by a pulley with a gear ratio of 1:1.

LiDAR model A1M8 from RoboPeak

A LiDAR was used to detect the end of the crop line by the sudden disappearance of the plant. LiDAR is the acronym for light detection and ranging, a system that uses laser pulses to explore the environment without contact. With this system you get a cloud point that gives the position of all visible bodies in the area of interest. It emits a modulated infrared laser signal, which is reflected and picked up by an embedded vision system.

The sensor was placed on robot's front at 25 centimeters from the ground. This algorithm consists of two parts, the first is the initialization of the variables, the second is the reading cycle the encoder data, in which the points received from the LiDAR that are not in areas of interest are classified and discarded, also within the cycle, the displacement data provided by the encoder installed on one of the drive wheels are also received. This data is stored incrementally separately for two zones (defined by trigonometric functions) and reset to zero when any of the points received by the encoder fall into one of the zones of interest, indicating that they have detected plants in that area. At the final part of the crop line, there is the condition to trigger the robot turn which is to compare the undetected distance of the most advanced area with the less one to determine when the end of the crop line is crossed.

MPU-9250

MPU-9250 is a multi-chip module (MCM) consisting of two dies integrated into a single QFN package. Hence, the MPU-9250 is a 9-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer, and a Digital Motion Processor™ (DMP) all in a small 3x3x1mm package available as a pin-compatible upgrade from the MPU6515. With its dedicated I2C sensor bus, the MPU-9250 directly provides complete 9-axis MotionFusion™ output.

This sensor was used for measuring the turning angle of the vehicle at the end of the crop line.

Battery

The selected battery features are described below.

Table 3. Battery features

Voltage:	12V
Lithium Cranking Amps:	120
Lead-Acid Replacement Range:	7-9(Ah)
Case dimension;	4.21” (107mm) length x 2.2” (56mm) width x 3.35” (85mm) height
Operating Temp:	40 - 140° (F)
Weight:	1.2 lbs
Max Charge Rate:	10A

Source: Own elaboration.

CONTROL ARCHITECTURE

Vehicle control was developed in C ++ language and Open CV libraries. All algorithms were programmed in both windows 10 OS and Ubuntu 16.04 OS. Windows Visual Studio 2017 was used as a compiler and ROS for Ubuntu.

The control of the robot can be done manually using a Sony dual shock 4 joystick, which is intuitive, ergonomic, and easy to get or replace, or automatically with our developed algorithm and computer vision system.

In the development of this robot, we are focusing on three tasks: crop monitoring, seed sowing, and spraying.

The algorithm was developed to start manually, therefore the program detects whether the Bluetooth joystick is connected or not, in case the control is not connected the program displays a message and closes. If there is communication with the joystick, the program waits for the buttons to be pressed.

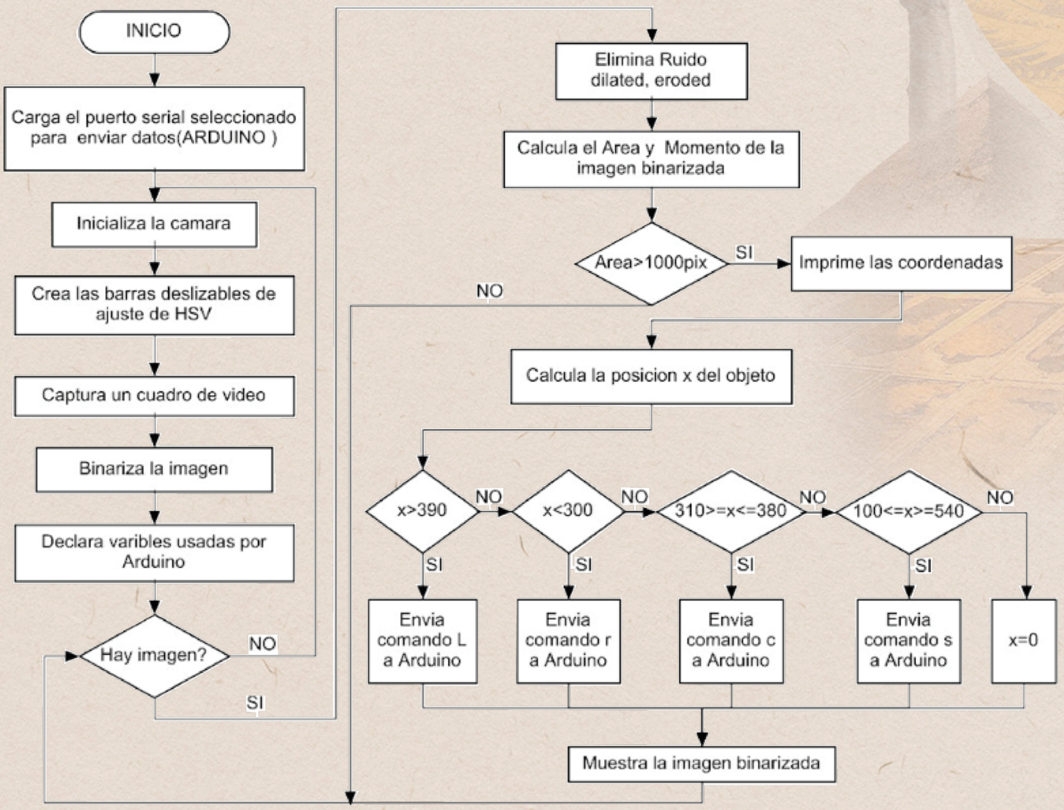
The left lever is used for robot movements; when moved upwards the vehicle moves forward; when the lever is moved downwards the vehicle moves backwards, the movements to the right and left generate a displacement in those directions with a wide radius of rotation, that is, an open turn. To make turns on its own axis, the R2 and L2 buttons are used. The R2 button generates a turn to the right and the L2 button a turn to the left. The circle button is used to stop the vehicle completely, until a movement button is activated.

When the vehicle is moving in manual mode, we can activate actuators for spraying trianglar button is used for seeds. With the "X" button we activate the autonomous system of navigation between plants, this system allows the vehicle to identify the midpoint between crop lines to move autonomously, while the camera detects the plants, and the computer calculates the trajectory. To detect the end of the row, we are using ultrasonic sensors, which detect the presence of plants on the sides of the vehicle. Once they do not detect anything for a certain time, the vehicle makes the turns and heads to the next line. This can be used to develop applications autonomously.

Artificial Vision System.

The programmed artificial vision system allows the vehicle to navigate autonomously between plant rows. This was done by implementing a type of control known as a visual servo, which uses artificial vision to determine the movements of motors.

Figure 3. Flow diagram of the servo visual control implemented



Source: Own elaboration.

The algorithm (Figure 3) consists of detecting the two rows of maize that are aside from the vehicle. Then we calculated the center of mass of these two rows which happened to be the exact center of the row. Finally, through serial communication the main computer sends signals to the Arduino for motor control. Figure 3 shows the operation of the control system for autonomous navigation. The system calculates the coordinate of the center of mass and compares it with established values. These values determine if the vehicle must turn to the right, left, or continue straight. Each action is sent to the Arduino through serial communication and a single character is used for each one. Itis very important to not saturate the Arduino with all the information for each coordinate that is being calculated, but only when it is required to do an action.

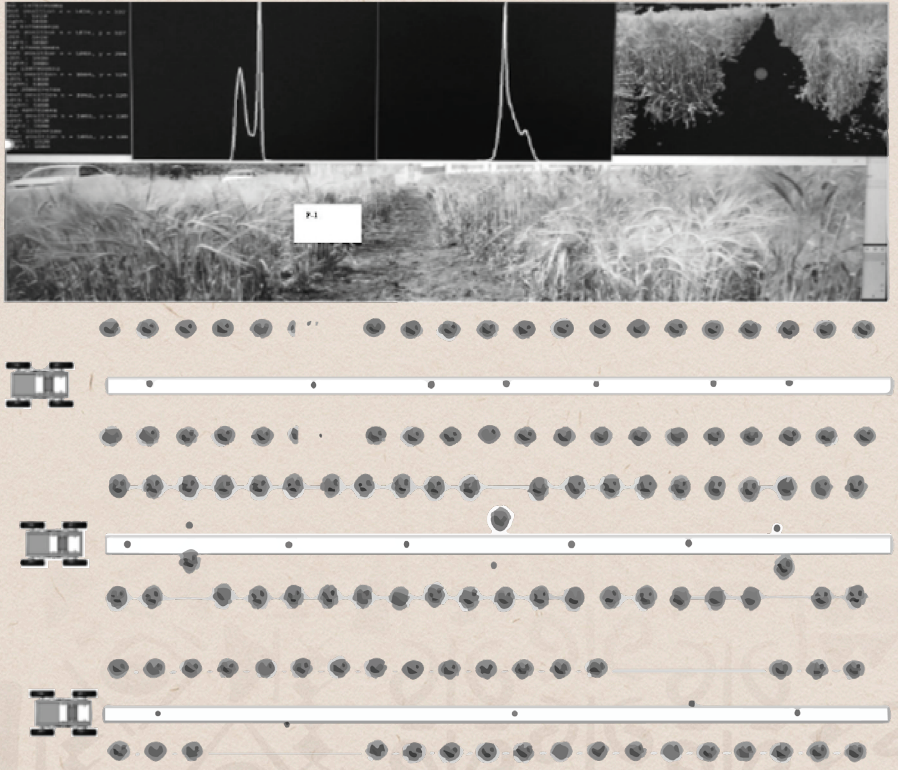
Computer and other Hardware

A Dell notebook with intel core I7 processor, 16 GB RAM and 250GB Hard disk. Two Arduinos Mega 2560, a LiDAR A1M8 compatible with Arduino, an incremental encoder, an IMU to measure the turning angle.

Software and strategy

Microsoft's Visual Studio 2017 was used as a compiler and OpenCV libraries in versions 3.0. and 3.1.

Figure 4. Information displayed by the servo visual control software



Source: Pictures taken by the author.

An algorithm that adjusts automatically to sunlight changes and detects the green color of the crop was developed. The advantages offered are many, such as saving CPU resources, fast real-time response, low cost, excellent autonomous navigation between crop lines; however, it is limited by the presence of obstacles, which cannot be detected yet. This algorithm allows for detecting the two sides of the row where the robot will navigate (Figure 4). Two rows detection allows for calculating the center of mass of the two rows, these coordinates are the exact center of the crop line. When the crop line is curved, left and right velocities are calibrated for each side of the vehicle. In order to measure the turning angle, an Inertial Measurement Unit (IMU) was used.

Results and Discussion of Machine Performance

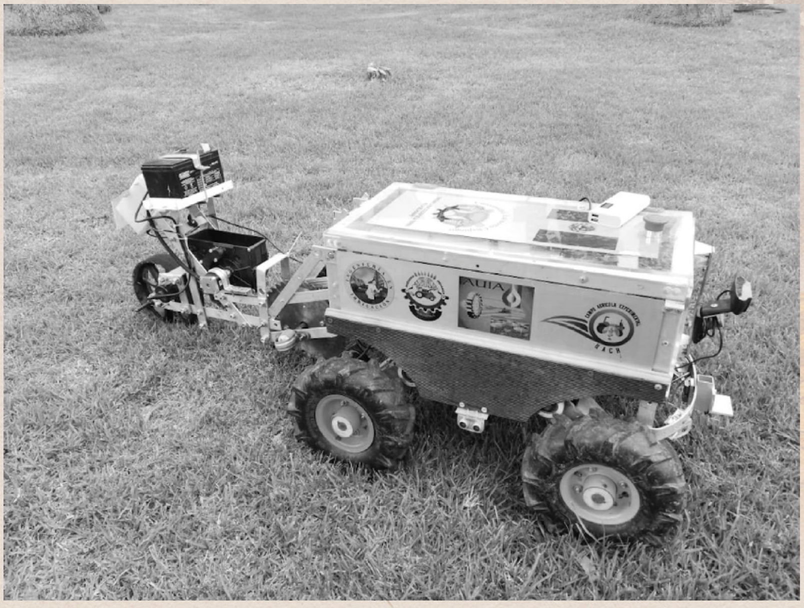
The first robot (Figure 5) for agriculture was designed and built at Chapingo Autonomous University.

Great performance when navigating autonomously between crop rows was achieved. Detection of the end of the crop line succeeded using a LiDAR.

To get better a performance out of the robot we decided to change to Ubuntu OS and use ROS (Robotic Operating System), which allows for parallel tasks, such as navigating and weed control, or navigating and spraying or fertilizing.

Based on the development of this first prototype new ideas emerge for the body and chassis. The process for protection as industrial designs in the Mexican Institute of Industrial Property has also begun.

Figure 5. First agriculture robot named “Voltan”



Source: Aguilar (2020).

CONCLUSION

The first agricultural robot was developed in Mexico at Chapingo Autonomous University. As a result of this development, the process for a utility model related to the suspension system developed was initiated.

Autonomous navigation between crop rows was achieved using computer vision. Detection of the end of the crop line was achieved using a LiDAR. The fact is that achieving autonomous navigation allows for crop monitoring, fertilizer applications and in general pest and disease control.

As for next stages in this project, there are equipment designing, including spraying systems, Autonomous seeders and fertilizers as well as the development of an autonomous recharging system in both energy and supplies (seeds, fertilizers, etc.).

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