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# Review of control on agricultural robot tractors

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**Abstract.** This article studies the most common methods of autonomous vehicle guidance, as well as a review of companies that have already developed their own self-guided tractors. The most common methods for autonomous guidance are through the position obtained from an RTK-GPS and by artificial vision. For both cases, sensors have to be implemented that help the task assigned, such as LIDAR sensors, proximity sensors, among others, that detect the tractor to know the working environment and define the correct route and even avoid collision, to comply with the assigned task, managing to improve production time and quality. The two guidance methods mentioned in this work fail to have error = 0, either by the type of sensor or by the technique used. Among the most commonly used techniques for obstacle avoidance are the possible field method or the probabilistic route planner.

**Keywords:** tractor, robot, agriculture, algorithm.

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## 1 Introduction

In the Food and Agriculture Organization [1], the world population is expected to increase by more than a third, or 2,300 million people, between 2009 and 2050. This growth rate is much lower than that registered in the last four decades, during which it increased by 3 300 million people, or more than 90%. It is expected that almost all of this growth will take place in developing countries, which implies an increase in the demand for products that a person can use daily. Food is essential for life, and these are obtained mainly from nature through agriculture, but due to various situations, the number of farmers is constantly decreasing, becoming a serious problem. The use of technologies in the agricultural sector is the solution to this problem; With these tools are provided to farmers that allow them to carry out the work they do daily more easily, quickly and easily.

Automation technology has aroused a growing interest in the design and development of new agricultural platforms that can provide feasible solutions to the challenges that exist in agriculture in countries such as: Japan, England, Spain, France, Germany and the USA, especially in these countries Labor is scarce, and production costs are constantly increasing. There are different aspects that an agricultural robot prototype must meet before entering a production stage, such as: reliability, protection and safety, system complexity and profitability Rovira-Más et al. [two]. The correct navigation of the robot is essential to achieve the success of these autonomous machines in the conventional farms that exist, the operation of these in the tasks for which they were designed must guarantee a minimum level of safety at the same time as the subsystems that compose it They cannot be too sophisticated for solutions to compete with the current team.

## 2 Description of the Problem

The growing demand for food and services has caused the food industry to have the need to generate more products in less time, so it needs more labor to achieve its objectives in its production lines and meet the demand for food. Many industries have implemented robotic technology in their production processes which has resulted in great savings of money and time since they have achieved greater production in less time Vogel [3]. The raw material demanded by the food industry is produced directly from the field, so this sector is being given more attention, implementing technology that allows agricultural production to be raised. The countries of greater development every day increase their demand for products so practical and highly effective solutions are highly sought to attack the growing overpopulation that is generated day by day.

Agriculture faces a difficult environment with a population of farmers that is aging and declining, a trend that will only accelerate more in the future Tractor and Pleasure [4]. There is much agricultural equipment, but the tractor has become one of the most selected to operate autonomously, the tractor works hard throughout the year, from the initial work of preparing the land, cultivation and harvests. With a workforce in decline and as many young people choose to pursue careers in other labor camps, autonomous tractors can be the solution to this growing problem. The development of autonomous machinery without a driver should be evaluated for its potential, but without neglecting or neglecting that they provide speed, precision and safety, making agriculture a more accessible and interesting profession. Achieving greater production with fewer workers is the main objective of technology. Robotic farms are currently only fiction, but they are not far from being a reality, with the evolution of technology, one day we can see how a fleet of tractors without an operator can perform the tasks it did with much greater speed and precision.

## 3 State of the art

In this section, we have a review and description of different published works that have a direct relationship with the work of this research. It is important to understand the evolution that has happened over the years and where it is directed in the future, being the basis of all research that is carried out. The different works mentioned are the product of the research carried out in different parts of the world and that directly impact modern agriculture, serving as the basis for the change and improvement of the techniques that currently exist.

According to Noguchi [5] a robot cultivation system includes: i) robot management system, ii) real-time monitoring system, iii) navigation system and iv) security system. For the present work, the last two topics will be addressed as study subjects: navigation system and safety system, as well as sensors, being relevant for the development of an individual tractor robot. Navigation systems are mainly carried out with the following technologies: a) machine guided vision and b) Real-time global kinematic positioning system (RTK-GPS).

### 3.1 Robot Tractor

The idea of automating functions in agricultural machines comes from the 80s, when the concept of precision agriculture begins. At present, autonomous systems are very useful because they simplify the daily tasks of the human being. In the agricultural sector, have an autonomous system, simplify time and improve production. Companies recognized in the production of tractors such as John Deere, Case IH, Yanmar, New Holland, among others, have developed this technology to modernize agriculture or have the concept to carry it out.

Some of the most prominent models of tractor robots can be seen in Table 1.

**Table 1.** Autonomous tractor models.

| Maker | Model | Power | Autonomy level |
|---|---|---|---|
| **John Deere** | 8320R | 320 hp (68.6kW) | Autonomous |
| **Case IH** | Magnum (redesigned) | 340 hp (250 kW) | Autonomous (concept) |
| **Yanmar** | YT488A | 83.1 kW | Autonomous |
| **New Holland** | T4.110F NHDrive | 88 hp (54.1 kW) | Autonomous |

In [6] it is mentioned that Case IH in Farm Progress Show of 2016, presented its concept of autonomous tractor, which can be operated remotely and does not have an operator cabin. The model is based on the Case IH Magnum line as seen in Figure 1. The tractor can be manipulated from a tablet, and the company qualifies the system as the future of Precision Agriculture. Using on-board sensors and video cameras, the tractor can identify obstacles and dodge them easily, in addition to the autonomous system, establishing the most efficient route according to the terrain and obstacles.

**Figure 1.** Case IH autonomous tractor [7].

The John Deere company in 2017 presented its autonomous tractor, the 8320R model shown in Figure 2, which was put on the market in Denmark [8]. John Deere autonomous models have a system called "AutoTrac Controller", this system is what allows the autonomy of the tractor and can even be adapted to non-brand tractors with the autonomous Plug and Play kit [8]. This kit has a laser scanner that allows you to detect obstacles up to a maximum distance of 100 meters.

**Figure 2.** John Deere 8320R Tractor [9].

On the other hand, the New Holland company designed the NHDrive Figure 3, an autonomous tractor that can work on different day and night agricultural tasks. The work can be supervised by a remote Tablet or from the tractor cab and also has complete autonomy, in which there does not have to be face-to-face supervision by an operator [10].

**Figure 3.** NHDrive, autonomous tractor New Holland [11].

Yanmar tractor producer, presented its autonomous tractor in 2018 Fig. 4, in Yanmar [4] it is mentioned that the developments are part of the project called Yanmar Robot Tractor. It works with SmartPilot technology (it is the brand of product lines that incorporate Yanmar autonomous driving technology [4]), which uses precision positioning data and robotic autonomous driving technology [12]. The system allows a single driver to operate two tractors in coordination (a tractor robot and the tractor manually manipulated by the operator).

**Figure 4.** Robot tractor YANMAR [13].

Autonomous tractors represent the evolution of those ideas about automating processes in the agricultural sector. The advantages of working with this equipment, is directly reflected in the production, both in precision and in time. Some of the autonomous commercial tractors can still be operated manually, which allows, during the day, a person to operate the tractor and at night to follow the production activities autonomously.

### 3.2 Machine vision to robot tractor

Currently, there are different guidance techniques or trajectory tracking for mobile robots, one of the most used is guided by cameras; image processing is indispensable for this technique; With the cameras, you can obtain images of the road to be processed and in this way differentiate green plants (crops and weeds) from the rest (soil, stones and others) as mentioned in Guerrero et al. [14]. In addition, based on the geometry of the system, straight lines can be assigned to the image as a reference of the path between plots.

Based on English et al. [15], Vision-based identification methods require algorithms that are capable of functioning correctly in situations of high or low light, day or night. To achieve the guidance of autonomous vehicles in agricultural fields, the detection of crop rows is required, which turns out to be a difficult task if the equipment and knowledge necessary to carry it out is not available.

As mentioned earlier, the detection of plant spacing within the row requires considerable time for a solution and work especially if this process is done manually. In Nakarmi and Tang [16] by using a state-of-the-art 3D vision sensor based on the flight time (TOF) of light that accurately measures corn plant spacing information with an average standard deviation error of 1.60 ± 2.19 cm, making way for the automation of this process to be used in tractor robots.

Based on the work done by Jiang et al. [17], by means of an automatic algorithm, rows of crops can be identified through different steps; The knowledge provided by an expert would achieve a combination between the algorithms, improving detection and reducing lateral error. The use of a neural network for the classification of plants and weeds, artificial vision for the detection of rows of crops, diffuse systems to avoid obstacles would integrate a robust and automatic system for guiding mobile robots through agricultural fields.

According to the research of Meng et al. [18], trajectory tracking techniques that use vision systems present a common problem, ambient lighting, a problem that currently affects all existing vision systems equally, some in a lesser way; Given this, there are robust algorithms that allow improved monitoring even with unfavorable conditions; the use of sensors is necessary as an emergency stop to stop the system in case of failures or overflows.

As mentioned, the guidance of autonomous vehicles can be carried out through artificial vision, however, it is a complicated job, because it is difficult to detect crop rows; as mentioned in English et al. [19], the location of rows is estimated with a regression algorithm Support Vector Machine (SVM), which uses descriptors of color, texture and 3D structure, all thanks to a pair of stereo cameras. The system quickly learns an online model with minimum user input and subsequently said model is used to track crop rows. By the method used in English et al. [19], a wide variety of crops can be traced, with a Root Mean Squared (RMS) error of less than 3 cm. Similarly, online control results are shown capable of autonomously guiding the mobile robot for really long distances.

Artificial vision can not only be used to guide the vehicle along a defined path. For example, in Bao and Tang [20], it is mentioned that they worked with a self-guided tractor that navigates between the rows of crops; While doing the trajectory, it collects stereo images of sorghum samples as shown in Figure 5. The images are processed offline, with a semi-automated software interface the stem diameter is measured, as well as the height of the plant, the leaf area index (LAI) and vegetation volume index (VVI). It is mentioned that very similar results were obtained compared to the normal measurement.

**Figure 5.** Phenotyping robot without and with extension rig [20].

As is known, determining a route in an autonomous mobile robot is a very important process, especially when artificial vision is being used as a method. An important problem that exists when determining the possible routes is the processing of 2D images, because the fields have weeds, shadows, lighting variations, irregular backgrounds and other unexpected conditions that are not in the simulation. In Zhai et al. [21], stereo vision techniques were used to locate a correct route within the crop rows, concluding that it is a process that requires robust processing and is not accurate enough; due to this in Zhai et al. [21], a multirow row detection algorithm is proposed, based on binocular vision. It is also mentioned that the algorithm was validated with comparative experiments, obtaining very satisfactory results.

Other uses of artificial vision are obstacle detection, as mentioned in Ball et al. [22]. The navigation system used consists of three parts, vision-based obstacle detection, visually assisted trajectory guidance and an autonomous navigation system that generates routes to avoid collisions. In this work, multiple experiments were carried out in several weeks during day and night, managing to avoid obstacles, in addition, it is demonstrated that the robot can continue to operate after some interruptions in the Global Positioning System (GPS), visually following the rows of crops.

In García-Santillán et al. [23], a method is proposed to detect rows of curved crops and straight lines of cornfields. It seeks to obtain precise autonomous guidance and treatment of the crop, including weed removal, where weeds are identified as plants outside the crop rows. As expected, the quality of the images is affected by uncontrolled lighting conditions due to the agricultural environment. Another factor that affects, are the different heights and volumes of crops and weeds. The main contribution mentioned is the ability to detect curved rows of curves and lines that have a regular or irregular space between rows, even when both types of rows coexist in the same image field.

### 3.3 Real-time Kinematic-Global Positioning System

GPS systems are excellent tools for autonomous vehicles, due to their great location accuracy. In Meguro et al. [24] describes an autonomous mobile surveillance system, guided by several sensors, including an RTK-GPS, an area laser radar (ALR), a CCD camera and an omnidirectional vision sensor (ODV) for surveillance and monitoring. recognition. It is mentioned that the mobile vehicle can follow planned routes, which can be both straight and curved routes, obtaining in both cases excellent tracking accuracy, even if RTK fixed solutions are not available.

One of the problems when using guided navigation using GPS is its coverage. In Gan-Mor et al. [25], it is mentioned that the accuracy of GPS receivers can be improved by differential correction systems (DGPS). Since DGPS systems are generally expensive, it seeks to maximize business profit and minimize related errors. A deviation from a predetermined route was recorded on a three-point hitch implement, mounted on a tractor automatically guided by RTK-DGPS. It is mentioned that the records were made by paved and rough surfaces identifying that in the latter major deviations were made.

When working with an implement on a tractor, its distance must be considered in order to follow paths correctly. In Pérez-Ruiz et al. [26], it is mentioned that an automatic centimetre-level precision mapping system was used to evaluate geospatial mapping, using a single RTK-GPS system mounted on the tractor for location mapping. It is mentioned that the mechanical coupling interface between the tractor and the transplanted (for this case, tomato transplanted), was instrumented with orientation sensors to allow the calculation of the location of the avocado, without the need for another RTK system -GPS located in the implement of the tractor, reducing the cost of navigation equipment. It is mentioned that the system responded effectively, managing to produce high precision maps for the location during cultivation.

Path tracking with the help of a GPS system can be affected due to the orientation of the mobile robot. The location points obtained by the GPS are referenced to the earth's axis. When it is desired to give a specific orientation according to a known plane, there are some drawbacks that have to be corrected. In Noguchi et al. [27], a field robot was developed for an agricultural operating environment, which with the help of an RTK-GPS, a fibre optic gyroscope (FOG) and an inertial measurement unit (IMU), trajectory tracking was performed straight and curved, including rows of crops, obtaining very good results. The results of the RMS position error are less than 3cm, suitable for trajectory tracking.

As mentioned, one of the most used sensors for guiding vehicles in agricultural production is the RTK-GPS. Despite its high cost, this sensor is still used due to its high measurement accuracy. In Umsup et al. [28] an evaluation of the GPS sensors is made, which unlike the RTK-GPS, the cost is lower, due to the lower accuracy of the position correction. The experiments performed in Umsup et al. [28], consisted of three different environments, in the open countryside, near trees and similarly near buildings. The results show a standard deviation for each case, both on the longitude axis and the latitude axis. As expected, the data obtained does not have the same quality of precision, as would be obtained with an RTK-GPS, resulting in continued work with these devices despite its high cost, if the task requires good Quality in measurements.

A complementary or substitute system to that described in the previous section is the use of RTK-GPS to determine the position in which the mobile robot is in real-time with an accuracy of centimetres. The implementation of these systems turns out to be expensive, but of great benefit because of the advantages, it offers. In Takai et al. [29] a caterpillar-type tractor was developed that navigates autonomously in an open sky field using an RTK-GPS receiver and an inertial measurement unit (IMU), by means of a keyhole turning algorithm the tractor pitch is achieved. The best tests and results are obtained in open fields to improve the signal quality of the RTK-GPS, obtaining better communication with the satellites that use them.

Global navigation satellite systems are key for their wide range of solutions. The research conducted by Rovira-Más et al. [30] shows that regardless of the quality of the receiver used, multiple path errors occur in the field and some others are uncontrollable, being a solution to this that the robot continuously checks the consistency of the signal it obtains. Based on the results shown, they determined that it is convenient to integrate the navigation systems, but by carefully filtering the data to prevent erroneous information from affecting the navigation cycle. The quality of the system gives the robot long-term stability in agricultural fields where the signal is unpredictable and the reflections cause sampling errors. The use of complementary sensors helps to improve navigation in situations where the quality of the GPS signal tends to fail, giving the robot robustness to face the situation mentioned above.

The correct follow-up of a trajectory is very important regardless of the purpose for which a tractor robot is destined, on this it depends that the actions are carried out in the places they determined; With the use of RTK-GPS we can provide these vehicles with a high precision sensor and with which you can know in real-time the position in which this is in the different existing formats. In Jilek [31], very good results are presented in which the predicted lateral error is less than 1 cm and they achieve this even in prolonged turns.

The IMU sensors are the main complement of the guidance systems through RTK-GPS, through these we can know the orientation of the robot, even more specialized sensors have the absolute position as an output, with this we can know the position with respect to a frame global and with which the RTK-GPS are oriented in the same way; Knowing this data is of the utmost importance if you want to know the phase shift between the reference point or path and the position of the tractor robot. The work done by Xiang et al. [32] presents the development of a machine to automatically transplant rice as shown in Figure 6, for this purpose different sensors and actuators were used, including RTK-GPS and IMU as a positioning and orientation system. The use of these sensors for guidance has a lateral error that ranges between 1 and 20 cm depending on various factors mentioned above.


**Figure 7.** The automatically guided rice transplanted [32].

Tractor robots are very useful to facilitate the work of farmers, but not only that, but some of these are destined to perform agrochemical spraying, which has harmful effects on the health of those who carry it out, even with protective equipment. With the use of robots, it is also intended to reduce the time in which it is carried out, subtract the farmers from it in order to protect them from accidents and intoxication, this is the objective that was achieved when carrying out the presentation work by Han et al. [33], for this they developed an autonomous driving system using an RTK-GPS.

In Noguchi [5] for autonomous navigation of robot vehicles and vehicles, navigation sensors are indispensable Tillett [34], numerous types of navigation sensors have been proposed, such as GPS [24-34], artificial vision [14- 23], radar Reina et al. [35], laser Barawid et al. [36], ultrasonic sensors, among others. However, GPS has been used lately for guidance systems in today's agriculture. In particular, RTK-GPS is becoming popular as a navigation sensor because farmers seek guidance with more precision More et al. [37].

### 3.4 Sensors

Safety is a mandatory factor to consider when developing a product, agriculture is no exception, in the work done by Noguchi [5] there is the talk of a problem that has not been resolved in this area. Ensuring safety for both the operator and the robot's operating space is indispensable. In the USA especially awareness about security is extremely high. All standard tractors have safety mechanisms that prevent the vehicle from moving forward if the operator is not sitting in the seat. For these reasons, an autonomous vehicle, as it does not have an operator, must have a higher level of safety to guarantee its correct operation in the event of a failure, with a large number of sensors as shown in Figure 7.


**Figure 7.** The hardware of the robot tractor [29].

Operating heavy agricultural machinery on and off the field represents a challenge, if we add to this monitoring the environment to avoid accidents adds even more complexity. Before this, Bosch Corporation provides an enveloping detection system that allows completely new perspectives at work, for greater safety, comfort and performance Bosch [28]. The joint work of different tractor robots implies the interconnection between them and the knowledge of the variables of the environment to achieve their synergy and carry out tasks in less time and with better quality as shown in Figure 8. This type of systems is easily applicable to robot tractors, increasing safety and complying with the pre-production requirements. But as any change requires an awareness regarding the distribution of responsibilities between users and manufacturers. If the robot assumes full responsibility, there is an unlikely event of an accident, which leads to a huge increase in costs and difficulties to the progress of Noguchi robotization [5].

**Figure 8.** Robot farming system [39].

A sensor unit that is successful in detecting an obstacle is the 2D scanning laser, in the literature Noguchi and Barawid [40] has been described for a tractor robot. Since it is necessary to equip the robot with redundant and multi-stage safety systems, three types of obstacle detection sensors are implemented in the robot tractor. Figure 9 shows a 2D laser scanner connected to the front of the robot tractor. The laser scanner is a non-contact measurement system (NCMS), which can scan your environment with two-dimensional measurements of the distance and angle of the object with respect to the direction of transmission that is counterclockwise.

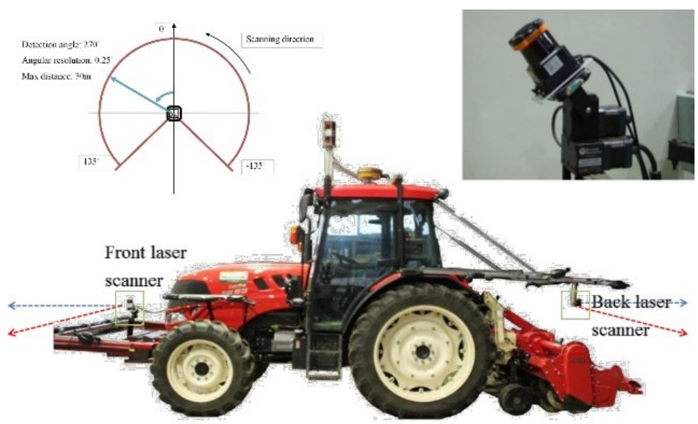


**Figure 9.** Laser scanner attached to the robot tractor [41].

Table 2 shows the lateral error that each author (from the literature consulted) has registered experimentally.

**Table 2** Lateral error of different experiments

| Title | Lateral error | Reference |
| --- | --- | --- |
| Development of an autonomous mobile surveillance system using a network-based RTK-GPS (2005, April). | 10 cm | [24] |
| Implement lateral position accuracy under RTK-GPS tractor guidance (2007). | 1 cm | [25] |
| Tractor-based Real-time Kinematic-Global Positioning System (RTK-GPS) guidance system for geospatial mapping of row crop transplant (2012). | 2.67 cm | [26] |
| Development of robot tractor based on RTK-GPS and gyroscope (1998). | 3 cm | [27] |

| | | |
|---|---|---|
| Performance evaluation of low-cost GPS-data logger module for smart-farm tractor (2019, August). | 43 cm | [28] |
| Development of a crawler-type robot tractor using RTK-GPS and IMU (2014). | 5 cm | [29] |
| The role of GNSS in the navigation strategies of cost-effective agricultural robots (2015). | 0-10 m | [30] |
| Autonomous field measurement in outdoor areas using a mobile robot with RTK GNSS (2015). | 1 cm | [31] |
| Development of an automatically guided rice transplanter using RTK-GNSS and IMU (2018). | 10 cm | [32] |
| Preliminary Results of the Development of a Single-Frequency GNSS RTK-Based Autonomous Driving System for a Speed Sprayer (2019). | 1 cm | [33] |

As you can see, the results vary radically despite using the same or similar sensors, this is due to the different techniques used for autonomous navigation of the system.

### 3.5 Navigation techniques

Route planning and monitoring are used to perform operations such as tillage, sowing and spraying. The work carried out by [42] proposes a route generation and tracking algorithm for a self-guided Korean tractor with a tillage implement that generates a route with C-type turns and follows the route generated in a rice field. To achieve this through a mathematical model, a waypoint route was generated based on the minimum turning radius of the tractor, the reference point intervals and the Limit of Boundary Offsets (LBOs). The calculation of the steering angle is done by comparing the angle of the reference point and the heading angle of the tractor.

In Wu et al. [43] the navigation of a mobile robot based on sensors in a narrow environment is developed using the combination of a fuzzy controller and a genetic algorithm, where the fuzzy controller provides the initial membership functions, and the genetic algorithm selects the best membership value to optimize the control and thus the navigation of the mobile robot.

It must be taken into account that, when the mobile robot is put into practice, there will be fixed or mobile obstacles. Being able to dodge obstacles is very important for the successful navigation of a mobile robot. In [44], a fuzzy genetic algorithm was used to plan a route that would reach the desired goal, avoiding all obstacles in the environment, using the ultrasonic range search sensor.

Algabri et al. [45] combine fuzzy logic with Genetic Algorithms (GA), Neural Networks (NN), and Particle Swarm Optimization (PSO) to optimize membership functions of the fuzzy controller and improve mobile navigation performance.

As mentioned, obstacle avoidance can be done through devices and algorithms. Among the most common algorithms are Potential Field Method, Cell Decomposition, Probabilistic Route Planner.

As mentioned in [46], the algorithm of Potential Field Method is based on building an attractive force for the target and a repulsive force on obstacles. The cell decomposition algorithm configures the space in cells which, with connected to generate a graph, which is applied to find the optimal path from the beginning to the objective of the same.

## 4 Discussion and future research

With the technological advancements that exist, agriculture has been one of the areas that least interest arouses in young people, causing a decrease in the labor force of this sector. This has increased the average age of the agricultural workforce, a factor that indicates that the profession is not being transmitted in the new generations. The use of increasingly large and sophisticated machines causes the soil to be compacted in a negative way, as well as environmental pollution caused by excesses in the use of chemical products such as fertilizers, which is leading us to negative results, reducing productivity. We could say that eliminating the use of this technique may be the solution, but the current demand for food is so great that not enough food would be produced to supply everyone, But developing larger and more powerful machines are not meant to be a solution either. Being able to produce tractors that have a degree of care for the work environment improved the situation and would allow the soil to recover faster. Human beings have superior intelligence accompanied by many senses that allow us to perform tasks such as manoeuvring agricultural equipment based on experience. Nowadays we can include many of these senses in a robot, in addition to being able to teach it to perform tasks that are sometimes very difficult for us, this in food production will be an indispensable system in the future and will come to improve our quality of life. Research especially in agriculture is on a good path and is an entire area of opportunity to make great contributions that can serve as an impetus for the development of new technologies that improve the way we produce food, reducing the times of production and increasing quality.

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