AGRIBOT: DEVELOPMENT OF A MOBILE ROBOTIC PLATFORM TO SUPPORT AGRICULTURAL DATA COLLECTION

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ABSTRACT

Precision Agriculture and agricultural practices that take into account environment protection, leads to several research challenges. Sampling scale and the precision required by these new agricultural practices are often greater than those required by traditional agriculture, raising the costs of production. This whole process requests an expressive number of studies in developing automation instruments. Amongst them, the use of remote sensing techniques based on On-the-Go sensors technology stands out, coupled to a Geographic Information System (GIS) adapted and developed for agricultural use. Therefore, the application of Agricultural Mobile Robots is a strong tendency, mainly in the European Union, USA and Japan. In Brazil, studies are necessary for the development of robotics platforms, serving as basis for semi-autonomous and autonomous navigation systems, facilitating data acquisition in the field. The greatest difference in the agricultural practices between Brazil and other countries is that, at other countries the skilled labor is not an issue and often the farm owner or family members perform field operations. Consequently, tasks automation can provide more comfort and reduce working days. Moreover, as it is considered a strategic sector, the government provides subsidies to producers in order to ensure at least part of internal consumption. The access to technology is also a differential characteristic, due to its high price or even unavailability in Brazil. Thereby, in Brazil, autonomous systems are supposed to meet the needs of the scarceness of qualified professionals, in face of the rising demands; in addition to serve as a laboratory for the development of national technology. The aim of this study is to describe the project of a mobile robotic platform designed to be used for the development of control systems, navigation and data acquisition technologies for agriculture. The main application of the platform is to perform remote sensing of agronomic parameters in large areas, at the most important Brazilian crops. The platform does not require actions with high power, as in traditional agricultural operations, but has to move efficiently in this environment. The platform should enable the massive data acquisition required to study the spatial variability, through sensors and equipment that will be embedded in the platform. The proposal is based on a systematization of scientific work containing the main methodologies and technologies employed in agricultural vehicles and robots, which were used as a basis for constructing the presented model. Furthermore, a preliminary study of working conditions and the desired characteristics of the project were performed. The design of the mobile robotic platform has been developed entirely in a virtual environment by 3D CAD software. This allows checking for interference between components during operation and, if necessary, changes in the design can be done. Moreover, data from the computer model are used to create the kinematic and dynamic models. It was established that the structure would be rectangular in gantry shape, with 1.80 m between the ground and the base of the chassis. The propulsion and the steering system are 4WD and 4WS, respectively, with each wheel fully independent from each other. A turbo diesel engine was used as main power source and hydraulic systems with proportional valves were used for power transmission. The actuators control is performed by dedicated controllers that receive the control parameters by network, and perform the control of the actuators in a closed loop control system. The data transmission between controllers and an embedded computer, which contains other sub-routines (localization, navigation, data collection), is carried out by a CAN fieldbus. Finally, a wireless network with Ethernet standard is responsible for the communication between the mobile robot platform and the control station.

Keywords: Agricultural automation, remote sensing, agricultural mobile robot, robotics, ISOBUS, control systems.

INTRODUCTION

Prior to the beginning of the study of robotics in agriculture, it is necessary to understand how the automation systems and the use of information technology are inserted in the agricultural sector. Basically, it is possible to say that these topics, as well as a roll of others, contribute to arrange the management system known as Precision Agriculture. Amongst the various approaches related to Precision

Agriculture, it is common to find quotes related with massive data collection, geo-referenced information systems, maps generation and variable-rate application. Meanwhile, these operations, when conducted isolated or without an appropriate management, do not provide profits or can provide confusing data.

As seen in the presented scenario, it is assumed that Precision Agriculture should be seen as a set of techniques for the management of agricultural production, which aims to reduce uncertainty in making decisions for better understanding field variables as well as managing these parameters. This method of management incorporates several areas of science, such as agricultural sciences, engineering, geostatistics, computer science, amongst others, resulting in a multidisciplinary system (Srinivasan 2006). Therefore, those involved with Precision Agriculture development and its use must have vast amounts of data, which are derived from multiple sources, to perform the tasks on making decisions (McBratney et al. 2005).

Precision Agriculture allowed changes in management of agricultural activities. One particular area that was managed as a whole has become fragmented into sublevels. Due to the increased amount of data to be processed, only certain operations can be performed using only human intervention. For this reason, it is important to note Precision Agriculture in terms of spatial and temporal units for decision making. Due to this fact, different forms of automation are required, especially in expensive crops.

In order to pursue the goal discussed above, there was an increased use of automated systems, equipment and procedures for collecting and processing data, which provided the development of new agricultural practices. These practices are based on technologies that were already available and were previously used in other areas, which were adapted to the agricultural environment, such as global positioning systems, geographic information systems, sensors, communication networks and interconnection of devices and controllers (Gozdowsk and Samborski 2007, Lee et al. 2010, Ahamed et al. 2011). Furthermore, it is important to develop technologies and devices for data acquisition and real time operations, sensor fusion and communication networks. Such actions aim to analyze the spatial variability using remote sensing as well as automating farm equipment, or providing support for new management practices (Auernhammer and Speckmann 2006, Auernhammer 2004).

Recently, concerns on the development of autonomous vehicles in agriculture have been raised, in order to support this demand. Most elaborate studies on driverless vehicles began to be developed in the early 1960s (Fountas et al. 2007). These initial studies were not successful due to their lack in comprehending the complexity of the real world. Most of them adopted an industrial-style to agriculture, where everything was known previously, and the machines could work entirely with pre-defined paths, like a production line.

The current challenge is to develop apparatus that are smart enough to work in a non-modified or semi-natural environment. These machines do not need to be as smart as a human being, but should present a reasonable behavior in recognizing contexts. Thus, it should incorporate enough artificial intelligence to work efficiently and safely for long periods of time, autonomously, in semi-natural environment, while performing an useful task (Pedersen et al. 2005). One way to understand this complexity is identifying what people would do in certain situations, and decompose the actions in the machine control (Blackmore et al. 2005).

In scientific literature, studies that aim to adapt the commercial agricultural machinery to produce autonomous agricultural platforms (autonomous agricultural vehicles or robots) are found (Reid et al. 2000, Keicher and Seufert 2000). Currently, there is a strong tendency to develop mobile robots and/or autonomous vehicles for use in specific tasks, causing an efficiency increase of operations and improved results when compared to the use of large tractors and traditional accessories (Blackmore et al. 2007), as can be seen in Reid et al. 2000, Mogensen et al. 2007, Reske-Nielsen et al. 2006, Blackmore et al. 2007. However, the development of specific platforms presents two main challenges (Blackmore, Fountas, and Have 2004): developing an adequate physical infrastructure for the agricultural environment and an electronic architecture for integration of the various electronic devices.

At this point, it is interesting to compare the objectives of the use of autonomous systems in Brazil, Europe, Japan and United States. The greatest difference is that in these countries, unlike Brazil, the skilled labor is not a problem, and the operations are often performed by the owner or family members. Thus, task automation can provide comfort and reduction of working hours. Moreover, as this is a strategic sector, government provides subsidies to producers, ensuring the production and blocking the entry of imported products. In Brazil, autonomous systems aim to complement the shortage of professionals due to the rising demand in this field, in addition to serving as a laboratory for developing national technology.

Considering this context, the aim of this paper is to describe the development and implementation of a modular robotic platform for data acquisition and research of new technologies for remote sensing in agricultural environments. The robotic platform has a multifunctional characteristic that allows the coupling of modules for infield data acquisition by means of sensors and portable equipment. The acquired data will be used in the study of spatial variability. The project aims to incorporate design characteristics that are able to enhance the remote sensing activities in agricultural environment, working in perennial, semi-perennial and annual crops.

DESIGN OF THE MOBILE ROBOT

Concerning the mobile robotic systems, there are technical factors that hinders the viability of these projects. The main factors are its interdisciplinary character and the requirements for operation in real time (Yavuz 1999). It is assumed that mobile robots are designed, built and tested all over the world. However, despite this popularity, the discussion about complexity of the structural design and the basic mechanisms of operation is often obscure or concentrated in the lower part of the work.

Yavuz (2007) performed an analysis in the literature in order to indicate the areas where there are greater focus of research concerning robotic systems. The main topics and related articles were: decision-making mechanisms; data acquisition subsystems; data and signal processing subsystems; adaptive control and artificial intelligence subsystems; computer hardware subsystems; operating software and related issues subsystems; control structure software and related research; sensing systems and related research; actuator systems and their subsystems.

Each of the topics mentioned above contributes to the overall functionality of the system, which could increase the list of applications and, in general, its sophistication. Although a project does not need to cover all these topics, it is possible to observe the complexity that involves the design, development and implementation of an autonomous mobile robot, particularly in terms of variety of interdisciplinary areas. As a result, there are not many robots in service or in household, as the projections made in the 1980 and 1990 stated.

In the initial phase of the design process, it is necessary to define the functionality, control architecture, navigation system, size of the robot, power supply and other requirements. However, selecting a solution amongst many options available for one of these requirements, is not simple, because the compatibility and suitability of any choice is dependent on the interaction of the subsystem of interest to the global system, and its performance to execute its task.

However, nowadays research on agricultural robots focused on the development of the robot, and not on the needs of agriculture related to robots. According to (Blackmore et al. 2007), this condition causes the robot projects to not reach the highest level of quality.

The approach adopted in this study starts with a brainstorm process. In the scientific literature, it is possible to find some studies that aim to define the design parameters and customer requirements for an agricultural mobile robot project (Sørensen et al. 2008, Sørensen et al. 2010, Sørensen et al. 2006, Sørensen et al. 2007, Tabile et al. 2011). In those researches, it was applied the QFD tool in the process of design of an agricultural mobile robot, following the model presented by (Chan and Wu 2005). It is possible to evidence that, over the time, new comparisons and conclusions are presented by the researches aiming to improve the model capability. Possible "customers needs" have been identified using several information sources such as: literature reviews, current research in robotics and selection of existing products.

During this stage, several customers' requirements were listed, each of them associated with a relative importance. Customers' requirements were divided into three main categories, called generic requirements. The main categories were defined as: mobility, navigation and autonomy and their respective customer requirements are listed below.

Mobility: reduces the amount of man-hour; able to transport an external module; easy to assemble an external module; easy to transport; easy to operate; flexible; good maneuverability; adjustable to the row size; low power consumption; operate on soft soil; operate in all stages of culture; uses renewable energy; light weight; small size; low noise.

Navigation: efficient; easy operator training; automatically data acquisition; reduces repetitive tasks; avoids damage to humans; animals; obstacles; etc.; minimum culture damage; minimal damage in the culture and soil; low operating cost; low purchase price; profitable; fast payback.

Autonomy: works without supervision; low maintenance; easy to start a task; operates without breaks; safety operation; easy to maintain; able to upgrade.

Customer requirements were converted into some design parameters that have potential to fulfill the customer requirements.

Mobility: operates without illumination; dimension; configurable by the operator; speed for transport; adjustable gauge; omnidirectional; wheel dimension; use commercial parts; system for join modules

Navigation: custom configurable; manual operation mode; semiautonomous; controlled by external modules; automatic stabilization; local positioning system; satellite navigation system; remote control.

Autonomy: susceptible to receive modular tools; remote surveillance; security system; easy maintenance.

The results were subjected to a functional decomposition and them, splited into main functions and alternative available techniques.

Mobility
Application: sensing; agricultural tasks
Environment: indoor; outdoor
Operational mode: autonomous; teleoperated; hybrid
Operation area: small (below 1 ha); medium (1 to 10 ha); large (up 10 ha)
Operation speed: slow (below 1 km/h); medium (1 to 10 km/h); fast (up 10 km/h)
Autonomy: small (below 30 min); medium (30 min to 2 hours); large (up 2 hours)
Payload: small (below 5 kg); medium (5 to 25 kg); large (up 25 kg)
Frame: gantry; rectangular; down; narrow
Energy demand: small (below 1 kw/h); medium (1 to 15 kw/h); large (up 15 kw/h)
Power source: gas/alcohol; diesel; battery; environment
Traction system: wheel; track; leg; hybrid
Actuators traction system: electric; hydraulic; pneumatic; gearbox
Steering system: differential steering; articulated steering; directional wheels
Actuators of the steering system: electric; hydraulic; pneumatic; gearbox
Suspension system: none; spring; compressed air; rubber bumper
Structural material: structural steel; structural aluminum; polymers; composite

Navigation
Position system: ultrasonic; GNSS; radio frequency; vision; odometry
Guidance system: digital compass; GNSS; gyroscope; odometry
Navigation system: GNSS; vision; touch sensor; ultrasonic sensor; optical sensor
Short-range obstacle detection: touch sensor; infrared; ultrasonic; laser
Long -range obstacle detection: laser; vision; ultrasonic; infrared
User input interface: radio joystick; cable joystick; wireless pc; mobile; web
Response robot interface: lcd display; pc monitor; speaker; SMS; web.

Autonomy
Mission control system: software; hardware; hybrid

Description of the electro-mechanical system

The agricultural mobile robot designed was named Agribot, with the aim to be a platform for the development of experimental control, navigation technology and data acquisition in the agricultural environment. The main application of the robot is to perform remote sensing of the most important agronomic parameters of Brazilian crops. The application will be executed in large areas and it does not require actions with high power, as in farming operations, but only to move effectively in this environment. Figure 1 shows an isometric view of the robotic platform with all the mechanical parts.

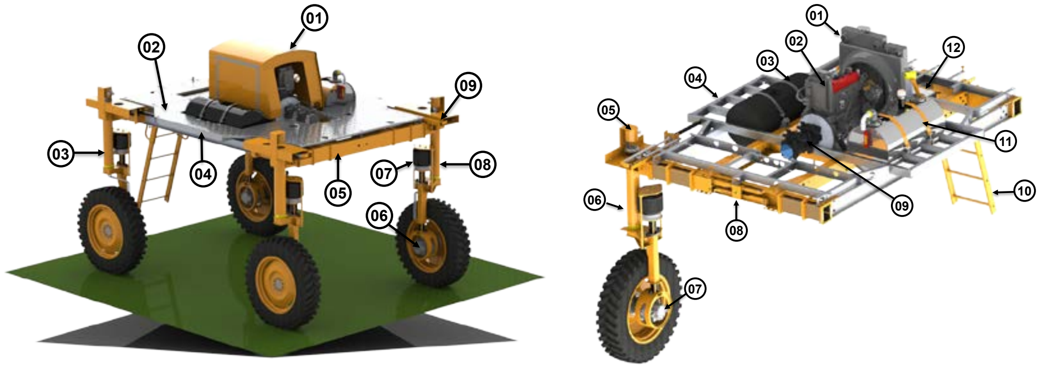

Figure 1. a) Isometric view of the robotic platform; b) General view of the main components of the robot

In Figure 1a: 01-Diesel engine and pumps system; 02-floor; 03-back wheel module; 04-secundary frame; 05- main frame; 06-propulsion system; 07-suspension system; 08-front wheel module; 09-steering system.

In Figure 1b: 01-cooler system; 02-Diesel engine; 03-fuel tank; 04-secundary frame; 05-hydraulic system support; 06-front wheel module; 07-propulsion hydraulic motor; 08-gauge adjust system; 09-hydraulic pumps; 10-ladder; 11-hydraulic fluid tank; 12-batteries pack.

Dimension and frame

As the agricultural mobile robot is designed to operate on the main crops in Brazilian agriculture, for almost the entire growth cycle and post-harvest, it requires structure versatility in order to attend all the situations. It was established that the mechanical structure would be in portico, and developed into independent modules called: main frame and wheel module. For this application, a platform was designed with four wheels and the movement in the field will be done in the space between crop rows, thus avoiding damage in the culture.

In the main frame the engine is fixed, which provides power to the steering and propulsion systems, hydraulic fluid and fuel tanks. Above the main frame there is a second structure called secondary frame, used to fix the floor of the platform.

The wheel module comprises an agricultural tire with dimensions of 9.5" x 24", the hydraulic motor of the propulsion system, the suspension system mounted with an air shock absorber and the steering system, which has an hydraulic cylinder as actuator connected to a rack, which drives a sprocket. The steering system allows to the wheel an orientation from -133 ° until 133 ° in relation to the origin of the system (wheel position where the robot goes straight). This range is enough to position the instantaneous center of rotation of the robot united with the center of mass, which enables the robot to turn around its own axis.

To allow the robot to operate in cultures with different intra row distance, a main frame with capability to adjust the gauge was developed. This process is accomplished by a manually activated sprocket-rack system, which connects the left and right wheel modules in the main frame. There is one system for the front axle and one for the back axle, and they are operated independently. The minimum distance between the wheels is 2.25 m and the maximum aperture is 2.40 m, the ground clearance is 1.80 m, and the height of the center of mass is 1.5 m. With the settings chosen, the platform has the maximum transverse stability of 33° and longitudinal stability of 40°.

Power system

Diesel engines are the most common mechanisms used in agriculture. Its main feature is the high torque generated even at low speeds. The power supply system comprises a Diesel-cycle engine model QSB 3.3 manufactured by *Cummins Inc*. It has four cylinders, 3.3 cubic liters, turbocharged and intercooled system which develops 56 kW (75 HP). Eco-friendly alternatives such as adoption of batteries or solar power would not provide sufficient energy to ensure the desired autonomy to the robot.

Propulsion system

The propulsion system is performed by hydrostatic transmission and consists of two variable axial piston pumps (swashplate), with electronic proportional control performed by solenoid. Those pumps, manufactured by *Bosch Rexroth AG*, are attached directly to the Diesel engine. Each hydraulic pump works in a closed circuit and is responsible for feeding two hydraulic motors, which are fixed directly to the rim of the wheel. The pump 1 supplies the front-right and rear-left motors through a tee-connector. Similarly, the pump 2 supplies the front-left and rear-right motors. The X form connection with the engines were positioned and connected to the pumps and ensured a differential hydraulic system, eliminating the requirement of an individual rotation control for each motor. In total, there are four radial piston hydraulic motors installed with two modes of operation (high and low speed), also manufactured by *Bosch Rexroth AG*.

Steering system

The hydraulic steering system consists of variable axial piston pumps (swashplate) with electronic proportional control actuate by solenoid manufactured by *Bosch Rexroth AG*, and fixed directly after the pumps of the propulsion system. The pump feeds four double-acting hydraulic cylinders, with through rod manufactured specifically for this application, which are controlled by a load sensing hydraulic control block. The hydraulic control block is manufactured by *Bosch Rexroth AG* and has four proportional valves with two ways, activated by solenoid. The system also presents a pressure control and relief valve. Each hydraulic cylinder is connected directly to a sprocket-rack system. The feedback of the position of each cylinder is performed by a linear potentiometer manufactured by *Gefran SpA* positioned parallel to the hydraulic cylinder.

Reserve system

A reserve hydraulic system is available, which is composed of a gear pump manufactured by *Bosch Rexroth AG*. The pump feeds a hydraulic control block manufactured by *Hydraulic Designers Ltd.* with one proportional valve with two ways, activated by solenoid. This circuit can be hereafter used to supply several additional components that may be inserted in the platform. The robotic platform also has a set of batteries connected in series to supply electricity power for the control systems, computers, sensors and other components that make up the structure. This system currently has three batteries of 12 volts and 170 Ah connected in parallel providing 510 Ah.

Suspension system

The suspension system is pneumatic and individual for each wheel module, with a stroke length of 0.3 meters. The suspension system is designed to absorb vibrations from rolling over rough terrain, and its main function keep all four wheels in contact to the ground. Although the system is passive, if necessary, the system can be update to an active model by adapting a control valve linked with a source of compressed air.

Kinematic Model

The Agribot kinematic model is based on the wheel dimension and position in relation to the center of mass (CM) of the robotic platform. To determine the CM, four scales are placed under the four wheels of the robot. Equivalent masses are calculated for all sides, and the proportion between them gives the position of the center of mass. It is assumed for the kinematic model that the orientation of all wheels is perpendicular to the instantaneous center of rotation (ICR), and that there is no lateral sliding during the movement. Figure 2 presents the position of the variables of the kinematic model in relation to the robotic platform frame.

The inputs of the system are: Turn radius (TR); Orientation of the TR in relation to the frame (β), which assumes values to $-\pi/2$ until $\pi/2$; Scalar velocity of the platform (V_{CM}).

The outputs are: Angular velocity of the platform (ω_{CM}); Orientation (δ_{i}), speed of displacement of the hydraulic cylinder ($v_{cil,i}$) and the angular velocity ($\mathrm{rot}_{\mathrm{W_i}}$) of the four wheels.

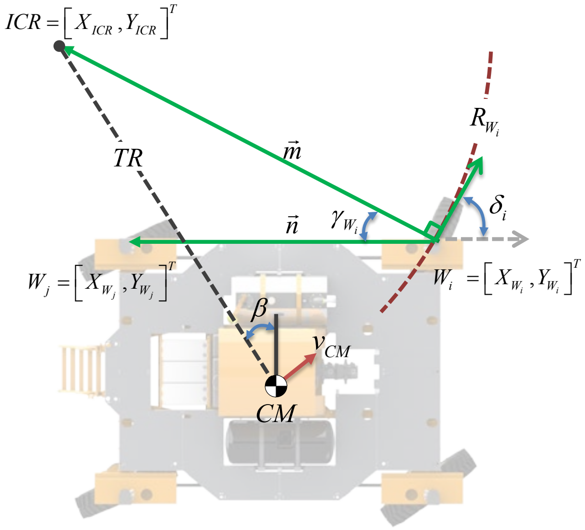

Figure 2. Variables in the Agribot kinematic model

It is assumed for the kinematic model that the CM is the origin of the coordinated system. The ICR can be calculated by the Equations (1) e (2).

$$X_{ICR} = TR.cos(\beta + \pi/2) \quad (1)$$
$$Y_{ICR} = TR.sin(\beta + \pi/2) \quad (2)$$

With the ICR position it is possible to determine the steering angle of the wheels. Two vectors for each wheel (Figure 2) are used in this calculation. The vector $\vec{m}$ has its origin joined with the position of the wheel that desires to find the steering angle (W_i) and finish in the position of the ICR. The vector $\vec{n}$ has its origin in the same point of $\vec{m}$ and is oriented parallelly to the frame ending in the opposite wheel (W_j). The signal of the determinant of the matrix M_i in Equation (3), which is formed by the position of the two vectors, is used to determine the orientation of the angle.

$$M_i = \begin{bmatrix} (X_{ICR} - X_{W_i}) & (Y_{ICR} - Y_{W_i}) \\ (X_{W_j} - X_{W_i}) & (Y_{W_j} - Y_{W_i}) \end{bmatrix} \quad (3)$$

The angle (γ_{W_i}) between the vectors $\vec{m}$ and $\vec{n}$ can be calculated using one of the properties of vector product as presented in Equation (4).

$$\gamma_{W_i} = arccos\left(\frac{\vec{m}.\vec{n}}{\|\vec{m}\|.\|\vec{n}\|}\right).\frac{|det[M_i]|}{det[M_i]} \quad (4)$$

The next step is to convert the angle between the vectors (γ_{W_i}) to the steering angle of the wheels (δ_i). For this purpose, some logic notations are made in function of the TR and the angle γ_{W_i}. The steering angle of the wheels (δ_i) are given by the Equation (5) until (16).

For the wheel W_1:

$$if\,(TR \geq 0 \; and \; -\pi \leq \gamma_{W_1} \leq -\pi/2) \rightarrow \delta_1 = \gamma_{W_1} + 3\pi/2 \tag{5}$$

$$if\,(TR \geq 0 \; and \; -\pi/2 < \gamma_{W_1} \leq \pi) \rightarrow \delta_1 = \gamma_{W_1} - \pi/2 \tag{6}$$

$$if\,(TR < 0 \; and \; -\pi \leq \gamma_{W_1} \leq 0) \rightarrow \delta_1 = \gamma_{W_1} + \pi/2 \tag{7}$$

For the wheel W_2:

$$if\,(TR \geq 0 \; and \; -\pi \leq \gamma_{W_2} \leq \pi/2) \rightarrow \delta_2 = \gamma_{W_2} + \pi/2 \tag{8}$$

$$if\,(TR \geq 0 \; and \; \pi/2 < \gamma_{W_2} \leq \pi) \rightarrow \delta_2 = \gamma_{W_2} - 3\pi/2 \tag{9}$$

$$if\,(TR < 0 \; and \; -\pi \leq \gamma_{W_2} \leq 0) \rightarrow \delta_2 = \gamma_{W_2} - \pi/2 \tag{10}$$

For the wheel W_3:

$$if\,(TR \geq 0 \; and \; -\pi \leq \gamma_{W_3} \leq -\pi/2) \rightarrow \delta_3 = \gamma_{W_3} + 3\pi/2 \tag{11}$$

$$if\,(TR \geq 0 \; and \; -\pi/2 < \gamma_{W_3} \leq \pi) \rightarrow \delta_3 = \gamma_{W_3} - \pi/2 \tag{12}$$

$$if\,(TR < 0 \; and \; -\pi \leq \gamma_{W_3} \leq 0) \rightarrow \delta_3 = \gamma_{W_3} + \pi/2 \tag{13}$$

For the wheel W_4:

$$if\,(TR \geq 0 \; and \; -\pi \leq \gamma_{W_4} \leq \pi/2) \rightarrow \delta_4 = \gamma_{W_4} + \pi/2 \tag{14}$$

$$if\,(TR \geq 0 \; and \; \pi/2 < \gamma_{W_4} \leq \pi) \rightarrow \delta_4 = \gamma_{W_4} - 3\pi/2 \tag{15}$$

$$if\,(TR < 0 \; and \; \pi \leq \gamma_{W_4} \leq 0) \rightarrow \delta_4 = \gamma_{W_4} - \pi/2 \tag{16}$$

In order to ensure the synchronized movement of the four hydraulic cylinders, according to the kinematic rules, the speed of displacement ($v_{cil,i}$) was calculated using the equation (17).

$$\Delta\dot{X}_{cil\,j} = \lim_{\Delta t \to 0} \frac{\Delta X_{cil\,j}}{\Delta t} = \frac{dX_{cil\,j}}{dt} = v_{cil\,j} \tag{17}$$

The angular velocity of the center of mass (ω_{CM}) in rad/s is calculated by the Equation (18).

$$\omega_{CM} = \frac{V_{CM}}{TR} \tag{18}$$

The maximum angular velocity allowed to the platform is 0.8 rad/s. The scalar velocity of the platform will be automatically reduced for values bigger than this maximum. With the position of each wheel in relation to the CM and the position of the ICR, the radius of the patch realized for the wheel can be calculated using the Equation (19).

$$R_{W_i} = \sqrt{\left(Y_{ICR} - Y_{W_i}\right)^2 + \left(X_{ICR} - X_{W_i}\right)^2} \tag{19}$$

Using the angular velocity (ω_{CM}), the radius of the patch of the wheel (R_{W_i}) and the diameter of the tire (d_W), the speed of the wheel, in RPM, can be calculate by the Equation (20).

$$rot_{W_i} = \frac{\left|\left(\omega_{CM}.R_{W_i}.V_{CM}\right)\right|}{\pi.d_W.V_{CM}}.60 \tag{20}$$

All the calculations are made for the four wheels. Finally, with the Agribot kinematic model, the desired angles (δ_i) for the four wheels are used as the setpoints for the steering control system.

Control system

Some of the recent applications of mobile robots use a distributed architecture based in fieldbus networks to attend the requirements of control and robustness (Blackmore and Griepentrog 2006, Blackmore et al. 2007). Fieldbus control systems replaced the traditional centralized control systems due to various benefits, such as reduced costs of implantation and in the number of wires, increased reliability and interoperability, improving the ability to reconfigure the system and ease of maintenance. Although the distributed fieldbus control systems offers several advantages over the traditional centralized control systems, the existence of communication networks results in more complex solutions for the design and implementation process. Networked control systems had additional problems inherent in control applications with fieldbus, such as delays, delay variation, limitations of bandwidth and data loss (Baillieul and Antsaklis 2007). Aiming to deal with the robotic platform requirements and control problems, a networked control systems architecture was adopted.

Power system: The control system of the Diesel engine is owned by *Cummins Inc*. and uses a SAE J1939 high layer communication protocol, based on CAN, with data transmission rate of 250 Kbit/s. The electronic control system requires the transmission of some periodic messages (by the user), otherwise the engine is turned off automatically. The input data of the system is the RPM of operation and the output are fault alarms and some engine operating parameters.

Propulsion system: The propulsion control system of the engines is owned by *Bosch Rexroth AG*. The electronic control system of the hydraulic system uses the CAN ISO11898 protocol with data transmission rate of 250 Kbit/s and 29-bit ID. The input data of the system are the displacement direction, motors speed, static brake status, and the output data are motor speed and transmission fault alarms.

Steering System: A steering system must ensure the synchronism between the wheels as a function of the maneuver performed and the vehicle geometry.There are some problems related to the robot wheel steering system, which challenges the development of the control system. The first issue is due to the hydraulic system delay. Differently of electric and pneumatic actuators that usually provides fast actuation on the controlled process, the hydraulic system used in the robot guidance shows a slow response time and high inertia. These characteristics influences the system performance and consequently the controller's choice and design. The nonlinearities in the steering actuators are another important problem. The spool of the electrical valves are controlled by a solenoid that is controlled by a PWM signal. The relationship between the displacement of the spool, the fluid flow through the valve and the PWM signal are nonlinear and will depend constructive parameters of the valve, the fluid conditions, etc.

Another problem is the inertia in the steering system due to the friction between the wheel and different terrains such as dirt, pasture and asphalt. The minimum value needed for the beginning of the steering movement is not constant and depends on the amount of inertia, which is being submitted to each wheel, and also depends on the robot mass distribution among the wheels. Moreover, there is a difference between the inertia related to static (when the robot is fixed) and dynamic friction (when the robot is moving).

The control system of the guidance hydraulic cylinders is done by an electronic control unit (ECU) model MC050 manufactured by *Sauer-Danfoss*. The system operates the solenoid of the *Bosch Rexroth AG*. load sensing control block. This control block has constructive features that allow precise control of the flow of hydraulic fluid, regardless of the pressure of the transmission line. This eliminates problems caused by variation of force required to the wheels movement, and hence the pressure in the line. This is caused by surface changes, external forces, weight distribution, among others. The use of a double-acting through-rod cylinder eliminates the problem of difference of flow and force existing between expansion and retraction of the cylinder.

The input data of the system are the PWM values (0-100%) that commands the opening and closing of the valve of each hydraulic cylinder. The output data are the analog values read from the linear potentiometers. The electronic control unit of the steering system is able to communicate in the CAN ISO11898 and SAE J1939 protocol.

CONCLUSION

The basic idea of the complexity of an autonomous mobile robot is illustrated in this paper, with particular focus on the design challenges. Initially, the possible areas of activity and the main consumer markets were identified. The operations that could be performed were identified and the most important features that make up the agricultural environment were defined. Considering these data, technical options were selected, in view of the set parameters of operation, and among those, the one that best fits the prerequisites of the project. The computational modeling was performed. The manufacture of this platform enabled the knowledge that the methodology used to develop the agricultural robot was efficient, and met all the needs.

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