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RESEARCH ARTICLE

AUTONOMOUS AGRICULTURE: NURTURING THE NOURISHER WITH EMBEDDED ARCHITECTURE OF MECHATRONICS

***Pavleen Singh Bali, Shuvam Gupta, Harivansh, K., Ankur Siwach, Raghav, A. K., Bhuvnesh Wadhwa and Gaurav Puri**

Mechanical and Automation Engineering (MAE), Amity University Gurgaon, Haryana, India

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ABSTRACT

Currently, there are significant challenges faced by the farming industry, which are a reduction in the available labour workforce, and a more 'corporate' style of farming. So such factors demand an increase in farming efficiency and productivity. In this regard, Autonomous Agriculture is seen as an effective tool for bringing together the areas of robotics, embedded systems and precision agriculture (PA) which not only deals with issues of agronomy but also provides better technology like “On-farm sensing and control” to actuate autonomous farm machinery for better farm management. It is a system-of-systems architecture, or unified framework, where a vital building block is the existence of two data sets used as links, or communication, between the various sub-systems. These data sets include a precision farming data set (PFDS) containing spatially precise navigation data (like how healthy is crop, map yield, moisture data, temperature, humidity etc.) for all autonomous machinery, and a precision agriculture data set (PADS), which is a continually evolving entity consisting more of agronomy data in relation to the crop for better sustenance, productivity and yield of the crop.

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INTRODUCTION

In India more than 64% of the population is concerned with Agriculture and as such input is of the majority but what about the output? The outputs are not satisfactory we still have to import a lot from overseas and on the other side talking about USA only 9% of the population is engaged with agriculture and surprisingly they are not only able to meet their needs but also has emerged as a major exporter of the world. So what causes the widening of the gap? The answer lies in the technology they implement and marketing strategies they adapt.

The benefits of “Autonomous Agriculture” are many as technological advances have brought about drastic changes in agriculture resulting in tremendous increase in production capacity besides replacing human effort and intervention in traditional farming machinery and other equipment. If embedded systems have changed the ways of farming, then the automation has only doubled that pace of change. Especially in India by opting for autonomous agriculture we can increase the annual yield by 39% which is a dynamic number besides raising the net profit by 8-9%. Automated farm equipment, needless to say, scores over human controlled equipment in terms of consistency and reliability. ***Guidance technology*** is already being widely used in self-propelled equipment to aid crop seeding and fertilizer application. These hi-tech, interactive systems provide information based on a variety of factors such as soil conditions, drainage and slope conditions, soil pH and nutrient status, etc. Prior to the use of these systems, farmers were often in the dark about soil output, and unpredictable weather conditions affecting crop quality and profitability. Moreover this kind of technology equips farmers with enough information to increase crop yield in a manner that is consistent with the best environmental practices for sustainable agriculture and as well as according to the market analysis (which will result in a sustainable profit and will motivate farmers to do more).

CHALLENGES

In the real world autonomous agriculture also faces several challenges like:

- Various Environmental issues regarding the implementation of the project and waste.
- Safety problems regarding the machinery for both humans and crops
- Technological issues regarding its behaviour and reliability

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****Corresponding author: Pavleen Singh Bali,***
Mechanical and Automation Engg. (MAE), Amity University Gurgaon, Haryana, India.

- Management regarding economic adoption, ease of use etc.
- Society regarding security and perception of the concept
- Economical issues regarding high capital costs and budget for the accommodation of the machinery.
- Mechanization pointing to the working capabilities of the machinery (Integrated operations & dependency of the machine.
- More structural and analytical model is given, for better interpretation of the required topic.

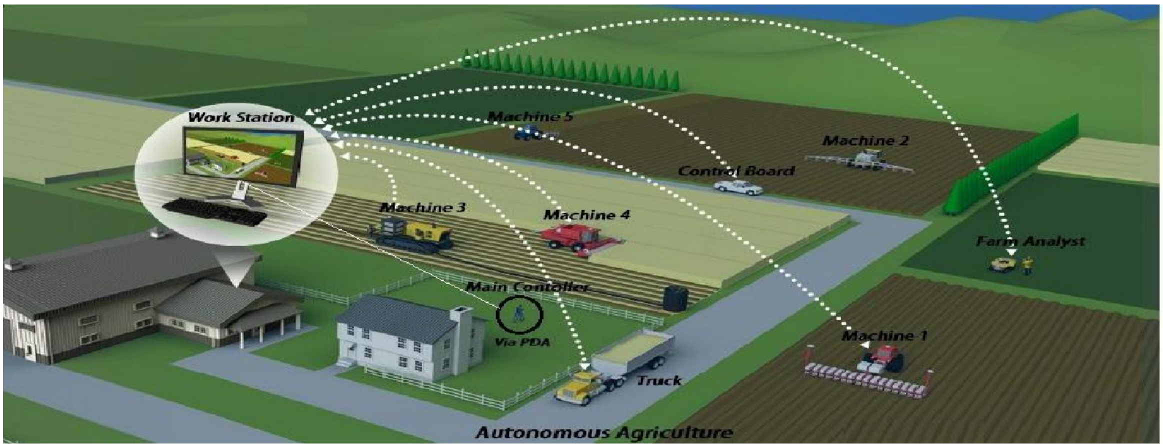

Fig. 1. Autonomous Agriculture Architecture

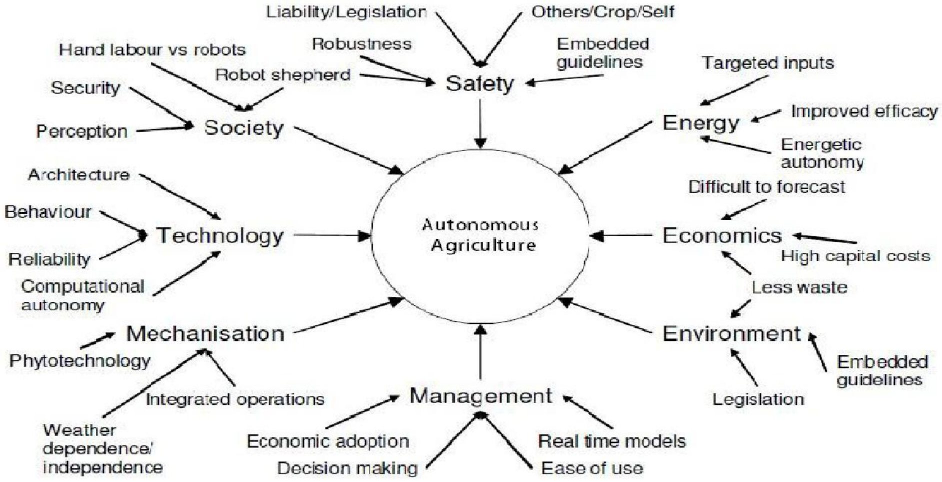

Fig. 2. Current Challenges of Conventional Agricultural Trends

REMEDY TO THE CHALLENGES

When we look at the major side of the project, it’s not a one day game but it demands a combined effort of both human skill and effective machinery. And for that we have to see various hardware, software and Implementation method to bring formation rather than information. So the Solution lies in both the ***Hardware*** coupled with ***Software*** specification.

HARDWARE SPECIFICATION

So the various hardware components required for the implementation and working processes are listed as under:

a. GPS (global positioning system)

Delivers an estimate of the robot’s position by measuring the differences between time-of-flight for signals from 3 to 12 geostationary satellites. Velocity and heading estimates are also possible to compute, based on Doppler effect of signals from the satellites. The velocity measurement accuracy is about 0.1 m/s. Basic GPS receivers have an position accuracy of around 15 meters 95% of the time. (100 meters if Selective Availability is on). An extended technology is DGPS (differential GPS) which has an accuracy of around 0.5 meters [Durr01]. Carrier Phase GPS, Dual frequency GPS and Kinematic DGPS are capable of delivering a position with errors between 2-20 cm and an attitude with an error of less than 0.1 degrees [Ocon96, Reid98]. Regardless of the type of GPS, the technology has limitations that make a GPS system insufficient as the single position sensor foran autonomous moving robot. A GPS system is therefore often combined with INS or odometry. The most common problems involve obstruction of line-of-sight to satellites, multipath problems and active jamming from other RF sources.

Inertial navigation system (INS)

Measures derivatives of the robot's position by gyros and accelerometers. Most equipment contains 3-axis pitch/roll/yaw gyros and 3-axis pitch/roll/yaw accelerometers. In this way attitude and position can be calculated. INS systems are prone to internal drift problems and must be periodically recalibrated to give full accuracy. INS systems are often used as a supplement to other position sensors such as GPS.

Wheel encoders (shaft encoders)

Sense the rotation of the steering shaft and wheel axles and convert these to change in orientation and position. Wheel encoders are often used for odometry as a backup or supplement to other navigational sensors such as GPS and INS. Examples of combining GPS with odometry can be found in [GaRi01]. A vehicle for automated harvesting is combining GPS, INS and odometry in [PiHa99]. The normal way to perform this sensor fusion is by Kalman filtering. This is a stochastic method known to compute the optimal linear predictor from two or many signals. In [HaHe01] a deterministic approach is combined with Kalman filtering for sensor fusion of odometry and inertial sensors. This approach is reported to improve the position estimates significantly compared with a pure Kalman filter approach. Compasses measure the orientation of the earth's magnetic field (most often only the horizontal component) relative to the vehicle and hence be used to estimate the attitude of the vehicle. Typical techniques are: gyrocompasses that uses gyroscopes pointing towards the magnetic north pole and flux-gate compasses that uses a toroidal magnet suspended in the Earth's magnetic field. This kind of sensors is very susceptible to local variations in the ambient magnetic field. Calibration is therefore essential. Also, compasses are known to be of limited value close to large metal objects and machine equipment. An alternative is to use a gyro, which provides a relative measure of the altitude of the vehicle.

Ultrasonic sensors/sonars

Determine distance to objects by transmitting a short pulse of ultrasound from the sensor. A receiver detects the reflection off objects ahead of the sensor, and the distance can be computed by measuring the time that elapsed between emission and reception. The sensitivity of a sonar sensor is cone shaped (typically 15-30 degrees cone) which means that the exact position of the object is unknown. However, the technique is very useful to detect free space, and is commonly used for obstacle detection in in-doors robotics. Another problem with sonars are so-called specular reflections. Specular reflections occur when a sonar beam hits a smooth surface at a shallow angle, and is therefore not reflected back to the robot, but outwards. Only when an object further away reflects the beam is a reading obtained, indicating a bigger free space than actually exists [Nehm00]. A typical maximum range with full accuracy for this kind of sensor is 5 meters (product information ActivMedia).

Infra-red reflex sensors

Most typically used for distance measurements by transmitting a modulated infra-red light pulse and measuring the intensity of the reflection from obstacles nearby. In practice, infra-red sensors can only be used for detection of objects, not for range measurements.

Infra-red detectors

Measure the infra-red emission from a human body. This kind of detector is often used in intruder alarms and could be used as an indication of human presence near the vehicle.

Laser range finders

Also known as Ladar or Laser scanners, work by the same principles as ultrasonic sensors with the important difference of using near infrared light instead of ultrasound. Instead of measuring the elapsed time between emission and reception, the phase shift of a amplitude modulated laser signal can be measured and used to compute the distance. The resolution and range is greatly improved compared to ultrasonic sensors and the problem with specular reflections is also much less pronounced. Typical accuracy is +/-50mm for single 180 degrees scan operations with a resolution of 0.5 degrees. Total range is between 50 and 150 meters (product information for the SICK laser scanner). A major limitation with this kind of sensors is the high price. This has restricted their development and effective use in ALV (autonomous land vehicles) systems [Durr01]. Another problem is the sensitivity to dust, rain and snow.

Millimeter wave radar

Promise performance that is not degraded by environmental conditions such as dust, rain and snow [Sing97, SuKu95, and ACFR01]. It is often considered to be a better alternative than Laser range scanners for the out-door automation. In [Clar99], Clark presents an analysis of how radar signals interact with common objects in typical field robotics locations. This leads to the development of natural feature extraction techniques, enabling suitable navigation markers to be identified from the radar measurements. It is also described how the identified features may be compiled into a map of the operating area.

Inclinometers

Used to measure the orientation of the gravity vector relative to the vehicle. In its simplest form they can be implemented as mercury switches. More sophisticated types measures the tilt and skew of the vehicle in degrees. Typical accuracy is less than 0.5 degrees. This sensor type is highly essential since it can avoid serious disasters that would otherwise be unpredictable for the autonomous vehicle.

Tactile/bump sensors

Used to create a "sense of touch" and are often used as collision avoidance sensors of last resort. They can either be treated as normal sensors or they can be wired directly into the low level control of the vehicle propulsion in such a way that they cause the vehicle to immediately halt.

Sensors

GPS is used for localization, i.e. determination of the vehicle's position and attitude and possibly speed. Compass may provide additional attitude information. However, they are known to be of limited value close to large metal objects and machine equipment.

- INS is also used for localization in combination with GPS. It may also be used for detection of collision with stones and trees.
- Ultra-sonic sensors are used for obstacle detection.
- Infra red detectors can be used to detect human presence.
- Camera can be used for obstacle detection and also localization. Stereo or single camera systems are possible choices.
- Millimeter wave radar and Laser range scanners can both be used for accurate detection and mapping of the objects around the vehicle. This can be utilized for obstacle detection and also for localization. Since laser scanners are known to be sensitive to rain and dust, the alternative of using milli metre wave radar should be seriously
- The Inclinometer is used to prevent hazardous movements that may jeopardize the stability of the vehicle.
- Engine rpm, measured wheel rpm and measured steering angle provide necessary feedback for the low-level control of speed and steering.
- Bumper switches are an important safety function. They should be connected to the Emergency stop of the vehicle in such a way that they cause the vehicle to halt immediately if activated. Hitting an obstacle physically should not happen if the vehicle's perception system is working properly. If it does happen, it indicates the uncertainty about the state of the world is too high to allow continued operation. However, the harsh environment for a forest vehicle in operation may make the task of mounting bumpers and delicate switches extremely difficult. The applicability of these and other sensors in forest environment should be investigated thoroughly. In particular, the operation of GPS inforest environment should be investigated.

SOFTWARE SPECIFICATION

The development work should obviously aim at producing software that will run on the eventual target machine. However, to speed up and increase the potential quality of the end product, alternative development platforms may be used during the development and research phase. The development of image analysis algorithms may very well be done using Mat lab. Series of test images can be shot and used for extensive "off-line" work with obstacle detection, human detection and localization. The developed algorithms should then be translated to the chosen run-time environment and tested under real-time conditions. If the suggested hardware architecture with an onboard computer and a radio Ethernet connected remote computer works out well, the development work will be greatly simplified and speeded up. The agricultural machine can be a huge and complicated software-intensive robot.

Software plays more important roles to guarantee safety and reliability. The software grows its scale and complexity beyond management capacity of a single programmer. Many machines follow the same history:

1. Mechanical control is replaced with electrical control with microprocessors, sensors, and actuators.
2. Electrical control gets more controlled by software but in an isolated manner. (Software is still enclosed in a mechanical component)
3. Electrical control gets integrated with a communication link. (Mechanical components are supervised by software)

Hierarchical systems

A *Hierarchical system* implements the tasks in a sequential and procedural way, much in the same way as one traditionally writes computer programs. The major procedures are often described as *Sense*, *Plan*, *Act*. The *Sense* part processes the sensor data and generates high-level descriptions of sensed objects. The *Plan* part normally involves serious modeling of the world and the interaction between robot and world. The actual planning is then performed in this model and the computed plan is finally executed in the *Act* part. Many drawbacks with this approach have been noted. One such is the fact that the world has often changed by the time the modeling and planning phases are completed. Another, more serious, is that the world simply cannot be modeled accurately since it involves too much noise and indeterminism.

Reactive systems

In a Reactive system, the overall task is broken down into goals that should be achieved. Each task is implemented as a reflexive behavior, where the robot generates an action as a direct function of the current sensor data. Maps of the environment are not allowed and state variables are avoided as much as possible. The function of the complete system is more described by these behaviors than by a data flow as in a *Hierarchical system.* The approach has successfully been implemented in a number of AGVs and other robots. The reactive approach has serious drawbacks as well, one of which is the total lack of memory or internal representations of the environment.

Hybrid systems

Most real applications use a mix of the two paradigms. These so-called Hybrid systems can be described by the design principle Reacts when it can, Plans when it must. The suggested robot architecture in the current project is essentially reactive, with behaviors responsible for the obstacle avoidance and path tracking. However, the overall control mechanisms and the routines for path recording are suitable for a hierarchical design. To define the route and actions the tractor should carry out, AgroNav Plan by GEOTEC was used. This software was a plug-in for AutoCAD that comprises of a number of scripts and tools to generate the final route plan. Agro NAV Drive was the software written by GEOTEC that ran on the GT2000 to control the actions of the tractor. The process starts by defining the tractor and equipment to be used and identifying the field boundary and existing structures in WGS84 or UTM coordinates. This can come from existing digital maps or can be obtained by driving the tractor around the field and logging the points. Next, the working direction is chosen, usually parallel to a long edge of the field. AgroNav Plan can then offer a set of suggested guidelines for the body of the field and the headlands (based on the working width and desired overlap of the implement) that the tractor could follow. These points can then be selected, one at a time by clicking the mouse, until the plan has been completed. If the user tried to define a route that cannot be achieved by the tractor, (e.g. defining a turning circle that is too tight) the software will alert the user. Operations or treatments can also be defined in the route plan as AgroNav Drive also has control over the three point linkage as well as implement on and off and the PTO. The final route plan (job file) is then stored as a text file that can be transferred to the tractor on a USB memory stick.

Coordination

A behavior-based system has to include a coordination unit that combines and synchronizes the actions suggested by the different behaviors. Overviews can for example be found in [Arki99] and [Murp00]. A number of standard methods exist:
The Subsumption Architecture is priority-based and lets the behavior with highest priority control the vehicle [Broo86]. This scheme is very fast but doesn't allow multiple behaviors to produce a combined action.

Motor schemas

A technique that performs command fusion by adding vectors representing the actions suggested by the different behaviors.

Fuzzy logic

Has also been used to perform command fusion from multiple behaviors [YePf95, Sera00, and SoSh95]. In [HaCa99], fuzzy logic is used in an autonomous agricultural vehicle for crop following. Fuzzy logic can also be used to express the actual behaviors in an autonomous vehicle. An excellent introduction to the entire topic of fuzzy logic for autonomous vehicle navigation is given in [DrSa01].

Utility fusion

Is an approach [Rose98] where each robot state is assigned a usefulness or utility measure? The utilities are combined with measures of uncertainty to evaluate actions based on kinematics and dynamics of the vehicle.

SYSTEMATIC APPROACHES

Aiming to replace the man in activities with high risk, or even in activities that require great efforts, and improve the efficiency of field operations, intensified research and development of autonomous robots for use in various areas in agriculture. There are several tasks that are currently performed by men and that, through the results of current research, may be replaced by autonomous robots, among these are:

1. Mappings of the planting areas;
2. Sampling the soil;
3. The analysis and identification of areas with infestations;
4. The analysis and estimation of production;
5. The fertilizer application and/or pesticides;

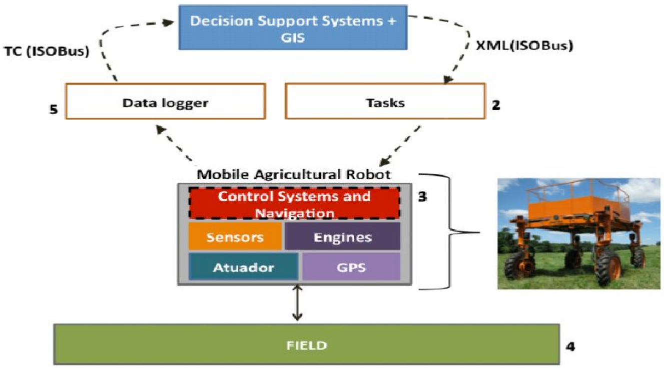

Fig. 3. Hierarchical Architecture for Integrated Systems

The Figure shows the hierarchical architecture for the integration of systems used, the flow of information from the system from the creation of the mission to his execution in the field, and return the data stored during its execution. Each agricultural operation, which can be called "mission" to be performed by a autonomous farm is the result of a series of processing and analysis of agronomic data spatial-temporal. After processing the data (geographic and agronomic), is defined a map of recommendation containing information about the mission, which is embedded in agricultural mobile robot with an autonomous navigation system, and used as reference for the implementation. The operating cycle of the robot shown in the Figure is divided into five steps:

1. Support System for decision making / GIS: Manage information about field operations, such as productivity, costs, machine maintenance, among other information, has generated research opportunities. The integration proposal envisages the creation of an algorithm that can export the geographic databases in default XML file maps of ISO 11783. That way can use GIS market with integrated farming systems that use the standard ISOBUS.

2. Missions: Maps containing information about the operations to perform on the field. These maps contain geographical information such as: boundary area to be used, known obstacles (trees, buildings), planting rows that need to be followed by the navigation system of the robot, and agronomic information specific about the "mission" that will be performed, such as: sequence of operations (capturing an image of the area, collect soil samples), sampling rates, the speed that operation must be performed, among others.

3. Autonomous agricultural robot: the robot agricultural has a series of devices (sensors and actuators), and motors, GPS and other electronic equipment. All these facilities are managed by autonomous systems of navigation, guidance and responsible for the tasks execution in the field. The robot has an electronic system that is in accordance with ISO 11783, which provides a standard for interconnecting electronic devices embedded and agricultural implements through a control network and serial communication (ISO, 2007). In Brazil, the ISO 11783 standard is supported by the Task Force ISOBUS Brazil.

4. Field: Areas planted with various crops (perennial and/or non-perennial), including: citrus and grains.

5. Results of mission: After execution of the tasks in the field, all operational data are exported agricultural machinery, imported and analysed by Geographic Information System. The data must be exported in standard ISO 11783 has conversion algorithms for reading through Geographic Information Systems (GIS) market available. Using the architecture presented above it becomes possible integration between the management systems and geographic information systems (GIS) with the control systems and agricultural mobile robot navigation for execution of specific operations in the field. The mobile robot has several agricultural systems of perception and action. Among the systems of perception include: Computer vision, inertial and GPS systems, scanner and Agronomic Data to be shipped, such as: maps of infestations, routes of operations. The actuation systems include: guidance and propulsion control, platform stabilization, robotic arm. The robot has a farm CAN bus for data communication and control that follows the pattern ISOBUS which was developed specifically for the agricultural area (ISO, 2007). The figure shows the agricultural robot.

Fig. 4. Various Utility Robots

Currently different research groups are working on the agricultural robot applying different areas of knowledge such as: robotic control, computer vision, among others.

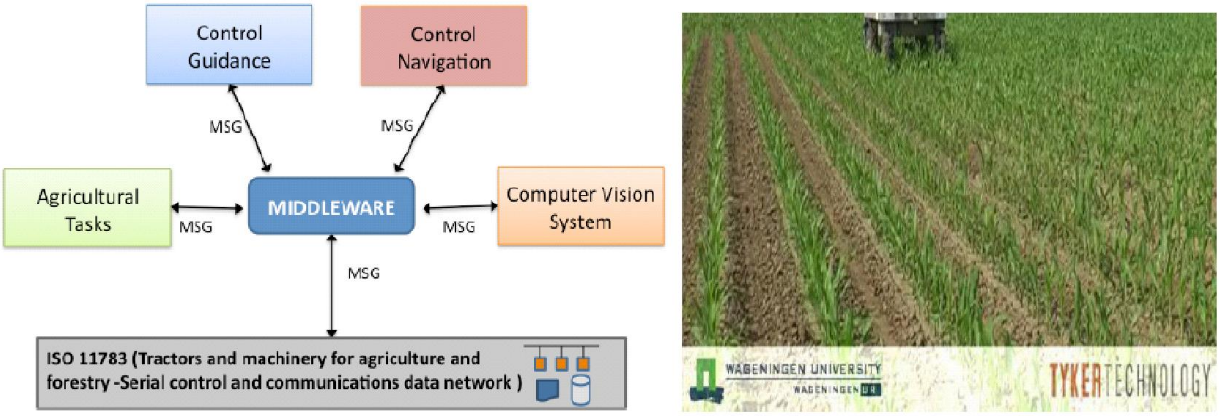

Fig. 5. Control & Navigation Protocols

The integration of embedded systems can increase the efficiency of the control system because it allow exchanges of messages between modules of perception, generating redundant information. An example is the possibility of the Computer Vision System to receive information from laser scanner module to check a reading done. If the camera's computer vision systems makes an data acquisition and identify a obstacle, can used the information generated by the scanner to Currently different research groups are working on the agricultural robot applying different areas of knowledge such as: robotic control, computer vision, among others.

Within this context, the middleware layer is used to exchange information and data between programs developed in different communication protocols, operating systems and platforms. All software modules, regardless of programming languages were developed, using an API to perform messaging with data from sensors and control and performance.

As can be seen, all messaging (MSG) on the CAN bus of the robot are sent to the middleware and are available for embedded modules, as well as the messages generated by these modules are sent to the bus. In the validation tests of the proposed architecture was used middleware OpenMQ which is free and is available on the market with uses in integration of distributed systems for many areas. The paper presented integration architecture for an autonomous agriculture to perform tasks using the concept of precision agriculture. In this line of research was necessary to create an architecture to integrate data generated from geographic information systems (GIS), or systems of agricultural decision support, with embedded control systems in agricultural robot. In order to maintain compatibility of architecture created, and the robot agriculture, with industry-standard farm machinery, such integration was done using XML files in the format defined in ISO 11783.

The model architecture and integration of data on the systems of perception and acting that was proposed, is consistent with the desirable requirements for distributed robotic systems, as presented by (Wienke, 2011). Among the needs requirements that are met by the proposed architecture are:

1. Portability: This property allows the control system is capable of functioning in different execution environments without changes. This is possible because the messages used by the control system are read in the middleware layer and are independent of architecture or platform that is generating this information.

2. Flexibility: is the ability with which the structure of a system of embedded software can be changed by inserting new software modules without the need to rewrite the control software.

Interoperability: Ability to run a set of systems for common purpose or domain, regardless of programming language, platform, or hardware manufacturers. The Table 1 shows all embedded modules on the agricultural robot and their development platforms.

The integration architecture through a middleware enables systems to sharing information, and increases efficiency in the process of decision-making information by different sensors that are available to being consulted and compared to their readings.

3. Interoperability: Ability to run a set of systems for common purpose or domain, regardless of programming language, platform, or hardware manufacturers. The Table 1 shows all embedded modules on the agricultural robot and their development platforms. The integration architecture through a middleware enables systems to sharing information, and increases efficiency in the process of decision-making information by different sensors that are available to being consulted and compared to their readings.

4.1 ALGORITHIMS & FLOWCHARTS

In agriculture, before the process of cultivation it is necessary that the land is ploughed and IR sensor is sensing that particular ploughed land for boring seed. The one infrared sensor is connected to the front edge of robot; other is at cultivating pipe which used to boring seed in land. The process of boring seed in a land is called pipe cultivation technique or pipe boring process. The mechanism of that process consists of two or three pipe section which is separated at a particular distance depending upon the crop. The rod or pipe is inserted vertically in the land at particular depth, corresponding IR sensor get interrupted and it sends signal to microcontroller through analog to digital converter. In case vertical rod is not inserted in land, microcontroller get understand that the land is not ready to cultivate or it is not ploughed or ploughed area of the land will be finished. There are two cases to sense the sensor as:

Case I: Obstacle is present: If any obstacle is present like hard rock in the way of vehicle, the infrared sensor gets automatically triggered through microcontroller. So microcontroller understand and ready to turn the vehicle in to 270˚ in forward direction and come back against same row per column and processed it further.

Case II: Completion of ploughed land: If there is no any obstacle is present in the way of vehicle, it will moves up to last end of the column. At that position, it tries to move 270˚ but cannot succeed and microcontroller understand to move next columns and in reverse direction. Now it again check for case (I) and move away further. And it repeatedly follows these two cases. When vehicle moves towards row per column, depending upon driver section of DC motor revolution, the stepper motor gets ON or OFF at a particular distance and seed gets boring through pipe mechanism which obeys the instruction of stepper motor. For driving stepper motor, a simple transistor which acts as a switch is used depending upon the signal carrying from driver section.

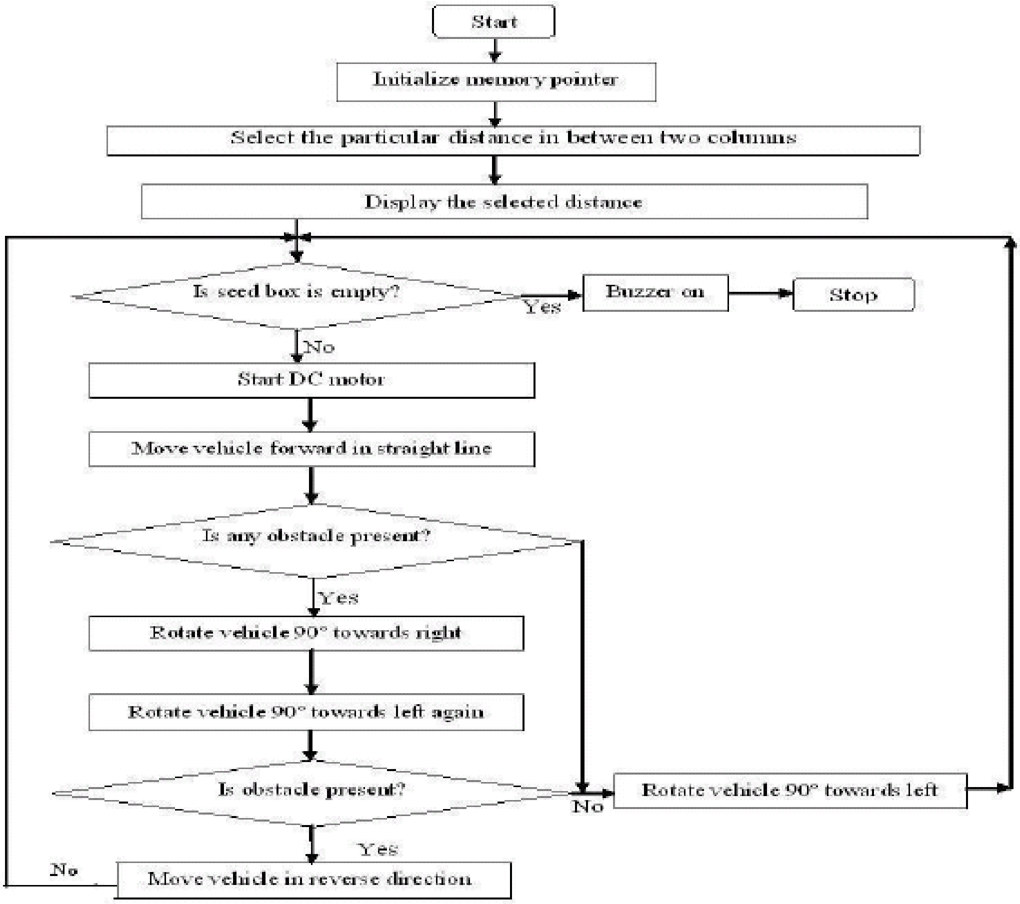

Fig. 6. Algorithm Implementation

The different distance is required for different seed cultivation, controlled by stepper motor driver section. And it will be get calculated by revolution per distance measurement of stepper motor driver section.

The algorithm for operating the robotic agriculture vehicle and whole system is implemented as represent in figure 4. First of all, it initializes memory pointer and select the distance between two or three columns depends on cultivation pipe. After selecting particular distance in between column, second step provides the distance between two rows by adjusting revolution of wheels per minute of stepping angle of stepper motor which controlled automatically by microcontroller, after selecting particular key from keyboard, shows on display board for conformation. After getting particular distance between rows and columns, the infrared sensor checks whether the seed box is empty or full filled, if it is empty, buzzer gets ON and vehicle will not starts, otherwise it starts dc motor and move vehicle forward in straight way. The obstacle detection and end of ploughed land can sense by following algorithm and operate it as explain in section III. After words, the vehicle moves in reverse direction and further processes the vehicle movement and controlling system. The system can be advanced for checking the moisture of farming land by moisture sensor and adjust the particular amount of water in soil (i.e. moisture of soil) according to seed and its requirement. It can automatically increase the moisture of soil in land, by giving water supply to this system. The system can further be modified to measuring various parameter in farming like crop growth, weed prevalence, its type etc. Also, one or many system can be monitored through GSM system.

1.Firstly whether its user friendly or not that is the working environment is simple for a layman or not. Whether it can work during rainy seasons especially in monsoon or not? What if the whole system has to work during the night hours? And how they will deal with the variably growing size of the plant or crop under consideration.

2.How will it keep distance between the rows without destroying the crops under consideration.

3.This behavior contains functions that keep the vehicle approximately on the path, and bring it back to the path when unacceptable deviations occur. A number of standard techniques for this task are described in the Section *Path Tracking*. A number of special conditions might call for special solutions and development in the area of path tracking and control algorithms:

4.How does the articulated joint steering affect the operation of the algorithms?

5.The Path Recording does not only record position, but also attitude, steering angle and speed. How can this information be utilized to improve the *Stay on path* behavior? One idea is to use the recorded steering angle as a constant offset at each location. In this way, the path tracking problem gets linearized and the controller will only have to make minor adjustments to keep the vehicle on the track.

6.Does an empty vehicle's behavior differ significantly from a loaded one? In such case, should separate paths be recorded?

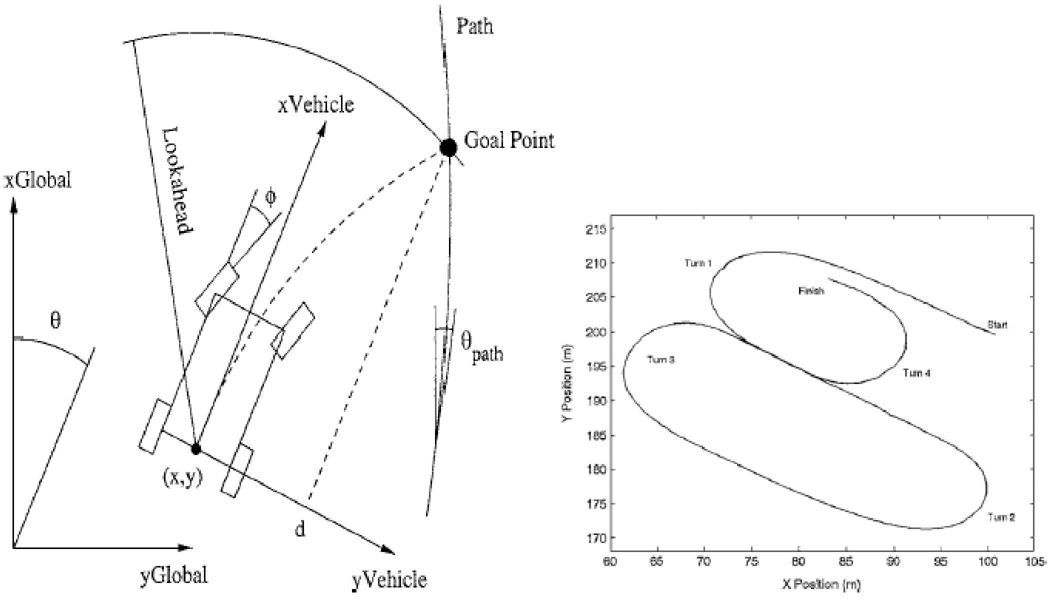

Fig. 7. Motion Planning & Trajectory Generation

TEST CASES

The Autonomous agriculture is a great solution to farming trends but it too has some sort of check points which needs to be highlighted for its proper and efficient working:

➢Avoid obstacles behavior

Once an obstacle has been detected in front or close to the vehicle an appropriate action has to take place. The exact strategy for this has to be developed. Obstacles appearing on what is assumed (according to the recorded path) to be free path should cause the vehicle to stop and await human guidance. Obstacles that are caused by the vehicle being temporarily off-track should allow the vehicle to adjust the steering angle and continue to follow the path. A number of available methods for obstacle avoidance are described in the Section *Obstacle Avoidance.* How the constrained move ability and large size of a fores machine affect the methods has to be investigated.

➢Collision handling

It is necessary to include a behavior to handle actual collisions, since the obstacle detection system at least occasionally will fail and the vehicle will hit a large tree or stone. The best design of this behavior has to be further investigated. A first approach is to simply stop the vehicle and alert the operator for assistance.

➢Avoid humans

The safest and easiest way to design this behavior is to stop the vehicle and alert the operator for assistance. This might also be the correct approach, since human beings should not be allowed in the vicinity of a forest machine in operation.

➢Other behaviors

The *Stay on path*, *Avoid Obstacles*, *Collision handling* and *Avoid humans* will be implemented in a behavior-based architecture. More behaviors can easily be added if needed. A *Start-up* behavior and a *Finish* behavior are examples of behaviors that should be included in a complete autonomous vehicle as part of the long-term vision.

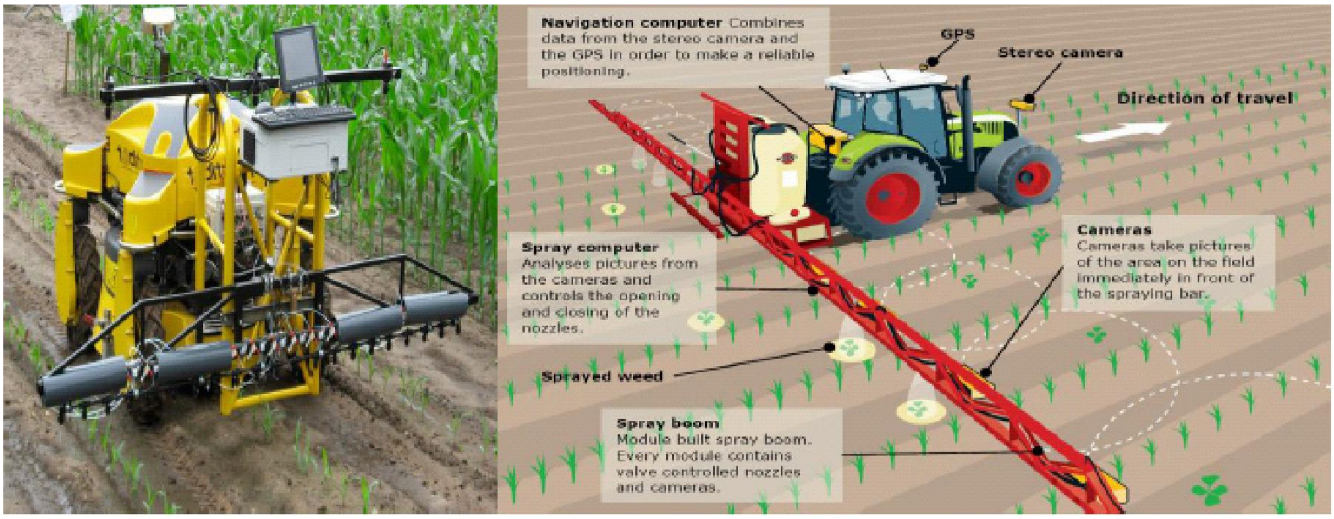

Fig. 8. Test Case Implementation

6 POTENTIAL RISKS & PROBLEMS

One of the key disadvantages of driverless machines for agriculture is liability. Unlike factory robots, agricultural machines must work in public. One news report of a malfunctioning machine that crashes into a neighbor's yard or of a machine that fails to recognize a dog or child and runs it over would create a firestorm of negative publicity. This type of accident is not new. Unfortunately, every year pets and children are hurt by tractors and other equipment. What is different for autonomous equipment is the perception that the accident was in part due the lack of a human to intervene. If autonomous equipment becomes commercially available, insurance companies would probably insist that a driver be present, if only to shut off the switch in case of a malfunction. This reemphasized that a driver would greatly reduce the benefits of this technology. Even if the driver is only present for safety reasons, he or she can still get sick, tired or need time off. If the driver is reinstated, a seat, cab and controls must be provided.

The liability issue is really an aspect of community acceptance of this technology. Community acceptance is an issue with all new technology and tends to be more important where the new technology forces major changes in long established ways of life and/or seems to present some physical danger. Not everyone greeted the arrival of automobiles and tractors with open arms. Motorized vehicles scared horses. Some people thought they were a safety hazard. Horse breeders quickly recognized that motorized transport would put them out of business. Today, new hog facilities are very efficient in turning corn into pork. Financing is available. The greatest challenge that investors who wish to build new hog facilities often find themselves facing is convincing the surrounding community to let them build.

Would people eventually become accustomed to autonomous farm equipment? Over time, they would probably become more accustomed, but perhaps only after insisting on a variety of safety measures.

In addition to a rider to hit the off switch, there might be legal requirements that fields farmed with remote control equipment be fenced to prevent children from straying into the path of the equipment. This would make the driverless equipment in the field more like the robot in the factory. For high value crops, such as the biotech pharmacy crops, extra safety measures might be affordable, but for bulk commodities, they may drive the cost out of reach.

The other problems associated with autonomous farm equipment can probably be overcome with technology. Better sensors and controls would allow the equipment to deal with plugging and malfunctions on its own. In addition to operating equipment, drivers are also collecting information (e.g., weed, disease and insect problems, soil issues, stand establishment). If they are no longer going across the field regularly, other ways need to be found to collect non-standard data. Better sensors would help. Improved scouting programs would be essential. Nevertheless, we will never have a sensor for every possible problem; a periodic human presence in the field is likely to be necessary for the near future. Autonomous farm equipment may be in our future, but there are important reasons for thinking that it may not be just replacing the human driver with a computer. It may mean a rethinking of how crop production is done. In particular, once the driver is not needed, bigger is no longer better. Crop production may be done better and cheaper with a swarm of small machines than with a few large ones. One of the advantages of the smaller machines is that they may be more acceptable to the non-farm community.

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