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# Development of Autonomous Agricultural Vehicle as New Trends of Agricultural Robotics

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**Abstract:** CCTV cameras are widely used to monitor traffic, but they often come with limitations that still force officials to check traffic flow manually. In this work, we introduce a simple and automatic method to measure traffic volume and vehicle speed by analyzing pixel patterns from CCTV video. Our approach begins by marking vertical and horizontal reference lines on each lane and collecting pixel information from these lines in every video frame. When a vehicle crosses these lines, the change in pixel brightness clearly reveals its movement. By studying these brightness changes, we can automatically detect vehicles and calculate key traffic parameters accurately.

**Keywords—** CCTV image big data; pattern change graph analysis; vehicle detection;

## I. Introduction

Video Image Detection Systems (VIDSs) and CCTV cameras are commonly employed for monitoring traffic conditions. Previous studies show that VIDSs can identify vehicles, measure traffic flow, and estimate vehicle speed. Despite these advantages, current VIDS setups face certain challenges. Since cameras are mounted at fixed and often limited viewing angles, only a portion of the roadway is captured, reducing the accuracy and number of vehicles detected. A similar need for improvement exists in the agricultural sector. Although many modern tools help ease farming activities, farmers still spend considerable time manually inspecting large crop fields. To reduce this effort, there is a growing demand for an agricultural vehicle that can move autonomously between crop rows and handle multiple operations efficiently. An ideal system should navigate accurately without drifting off its path, avoid obstacles, and choose the most efficient route across the field. This paper presents a prototype of an autonomous agricultural vehicle designed specifically for row-based crop layouts. The system integrates sensors with a NodeMCU controller to achieve real-time path detection and obstacle avoidance. The sensors continuously monitor the route to be followed, identify any obstacles in the path, and guide the vehicle back to its intended track if deviations occur. With these capabilities, the autonomous vehicle can systematically cover the entire field, significantly reduce inspection time, and enhance overall farming efficiency with minimal human involvement.

According to the Food and Agriculture Organization (FAO), the global population is projected to rise to nearly 9.1 billion by 2050. Meeting the food requirements of this growing population will demand at least a 70% increase in food production, with developing nations needing to nearly double their current output. However, traditional farming practices, combined with the steady decline in available agricultural labor, are making farming less efficient and economically unsustainable. In this scenario, the development of intelligent and autonomous agricultural machinery becomes crucial for enhancing both the quantity and quality of farm produce. Modern agriculture must also address critical issues such as excessive use of agrochemicals, energy conservation, environmental pollution, and the impacts of climate change. Automation has already shown promising results in improving agricultural productivity. This paper presents a comprehensive review of existing research on agricultural automation and highlights the global advancements made toward integrating autonomous systems into farming operations.

**Index Terms -** Autonomous vehicle, NodeMCU, Arduino's IDE, Sensors, REHA.

## II. Introduction

India is agriculture dominated country [1]. As population grows, need of growing crop increases [2]. So more production is required in less time is necessary. Time reduction can be successful if we introduce machinery in agriculture field. The idea of machinery in the agriculture field was involve long back. Farmers used different kind of equipment for different processes. Initially they just include some techniques with traditional way of irrigation, cultivation, cropping etc. but nowadays they prefer using the equipment available in the market. By these equipment they can do work efficiently and effectively.

If we see the history in agriculture, we can realize that agriculture emits so much occupation from manual to high level business where there is use of wide range of tools and equipment [3] with human and technology intervention. According to the changes developed in the society and growth of population researchers are looking toward the autonomous system which can do work more suitably with low cost. In early 1920 some of them develop a system which can run the vehicle on the field to do multiple works.[4,5] Then automatic vehicle, remote controlled vehicle, wired and human controlled vehicles were invented in date back to 1950s and 1960s. [6] Other combination of automatic and computer intervened equipment with some sensors like image processing sensor to

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give vision to machine as well as human were proceed in 1980s. This kind of system gives guidance too. In that duration Orange harvesting with programmed robot was also developed.[7] After that decade, things were changed, need of people and farmer needs became different. No-body wants to work for whole day in field only. So requirement of development and advancement in the agricultural field become necessary. Agriculture sector continuously changes into business since then. Also there were requirement of the machine which can travel on the agricultural field effectively with some extra accessories which can ease the work with lesser time. So, agricultural vehicle was come into account which can run on the crop field without creating problem in case of running and inspecting the crop field. Agricultural sector had utmost issues long with great precision ranked one to solve. Demand of agricultural vehicle contains quality to increase fertility, accuracy and also increase safety during operation with lesser time and cost. These were only possible because of advancement in electronics, computers and computing technologies. Some guidance technologies such as mechanical, radio navigation, optical guidance and ultrasonic guidance were developed and incorporated with the vehicle to perform desired work. [8,9]

After these experiments, robotic system comes which could made things autonomous that mean autonomous vehicle were developed which can run on the agricultural field and also do multiple works in single visit of field. Also reduce time and cost without involvement of any body. [10] Everything became autonomous. Then in agricultural sector the biggest task for the crop field is to inspect. For this, now, there are many products available in the market but we need a product which can reduce the inspection time as well as by giving some advancement in this, it performs more than inspection. For that researcher do work continuously. [11] They introduce many kind of vehicle including aerial and ground vehicle or robots etc. For effective work the agriculture vehicle should be compact and autonomous. The vehicle should be intelligent enough for navigation control for every field including in-line crop field. This is only possible by applying artificial intelligence to the system. [12]

So from the beginning, researchers were trying to make a vehicle for agricultural field to perform work. Firstly introduce some remote controlled vehicle then come to automatic vehicle and now autonomous vehicle. Remote controlled vehicle as name suggest that it controlled by wired remote where person had to present in the field to drive the vehicle. Then comes generation of automatic vehicle which was controlled wirelessly where person had to fully concentrated but there is no need of physical attention. But in an autonomous vehicle there is no need of person [13], but system perform specific work carefully according to the instruction given through codes. The vehicle has enough coding to make it intelligent for making decision. For these coding, many kind of Integrated Circuit Boards are available in the market like Arduino UNO, Raspberry Pi etc. Every board can connect with Arduino's IDE, where program can burn and we get desired output as per the program written in the IDE. Here I am using NodeMCU board. In any work field the interaction of autonomous vehicle should be systematic and appropriate [14]. Scientific literature shows many studies on autonomous robot for agriculture application [15][16]. Agriculture bots are made for cropping, for irrigation, for monitoring the health of crops, for inspection and many more. But hey are in static condition. They didn't move their self. Here in this paper, there is explanation regarding self-operating vehicle which runs in the field without any involvement of man power [17] and can choose its own path without any distraction, just by using some sensors and also it avoids obstacle present in the field. It can make 180 degree move and can select the optimum path again. All these done by coding and burnt the code in the board called NodeMCU. It need to provide battery backup by which it can run without connecting with laptop or computer or any wire.

**National Overview of Agricultural Automation**

The agricultural machinery market in India has experienced significant expansion, with an estimated compound annual growth rate (CAGR) of more than 10% during 2013–2018. Mechanization levels vary sharply across the country—states such as Haryana and Punjab exhibit high levels of automation, while many northeastern states still rely heavily on traditional farming methods. Factors such as rapid urbanization, increasing population, and the growth of non-agricultural sectors have contributed to reduced farm labor availability, ultimately affecting agricultural productivity. The Indian farm equipment industry, valued at nearly USD 6.5 billion, has shown strong and consistent growth in recent years. Studies suggest that the adoption of agricultural automation can enhance overall productivity by up to 30% while reducing input costs by roughly 20%. These trends highlight the critical role of mechanization and automation in strengthening India's agricultural sector.

**Challenges for Automation of Agriculture**

- Land holdings in India are generally small and fragmented, making it difficult to use large or advanced machinery.
- Farmers often face challenges related to the affordability and financing of modern farm equipment.
- The procurement process for agricultural machinery is often inefficient, and after-sales service quality remains poor in many regions.
- There is an excessive dependence on tractors, while other useful types of machinery remain underutilized.
- The agriculture sector was expected to employ nearly 205 million people by 2019–20.
- Around 60% of the rural population is engaged in agriculture and allied activities.
- Farm labour availability is projected to decline by approximately 26% by the year 2050.
- Most agricultural fields are small in size, making them unsuitable for operating large and heavy farm machines.

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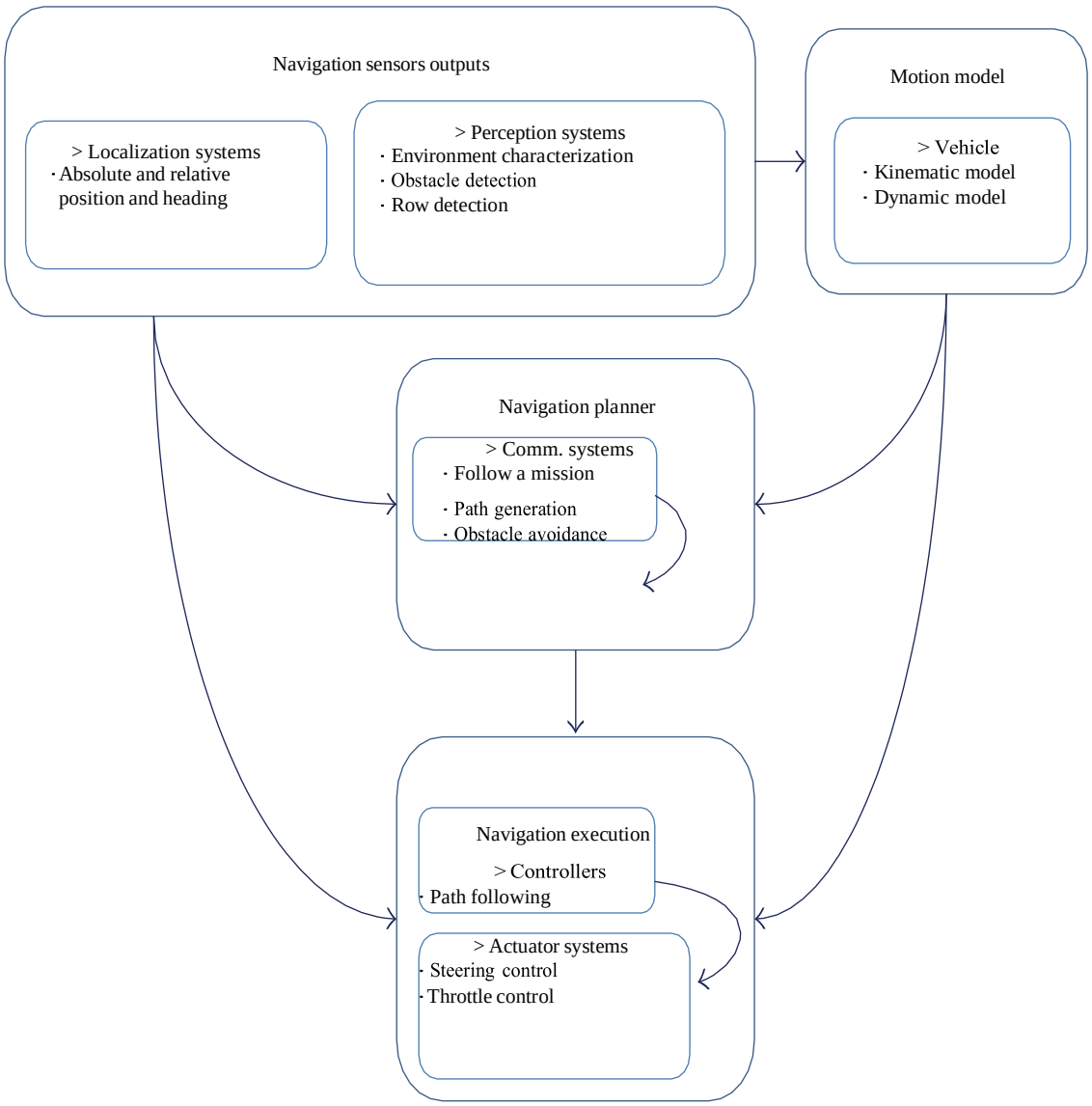
## III. Review of Literature

To achieve a truly autonomous agricultural system, the two major functional components—autonomous navigation and autonomous task execution—must be combined into a unified hardware and software architecture. This integrated system should share sensors, planning modules, and decision-making processes for both movement and field operations, while also minimizing the amount of hardware required without compromising performance. The architecture must be designed to accommodate a wide range of sensors, actuators, and commercial agricultural devices developed by different research teams. In addition, it should support multiple standard communication protocols commonly used in modern agricultural technologies. A modular design is essential to ensure smooth interaction between sensors and devices, efficient organization of perception and processing units, and flexible actuation control, especially given the diversity of available technologies.

As an initial step toward this goal, this paper concentrates on developing an architectural framework for mobile autonomous vehicles that can work cooperatively as a fleet in agricultural environments. For such systems to be practical and effective, features such as hardware reliability, plug-and-play capability, and ease of programming are critical. Alongside these, modularity, expandability, ergonomic design, ease of maintenance, and cost-effectiveness are also vital to encourage wider adoption of autonomous systems in real-world agricultural settings.

The proposed configuration incorporates these essential characteristics, while additional considerations are explored in subsequent sections. The objective is to offer manufacturers of agricultural machinery practical design guidelines for automating next-generation equipment, particularly in the rapidly growing field of precision agriculture, where durable and efficient solutions are in high demand.

Autonomous guidance framework




(a)

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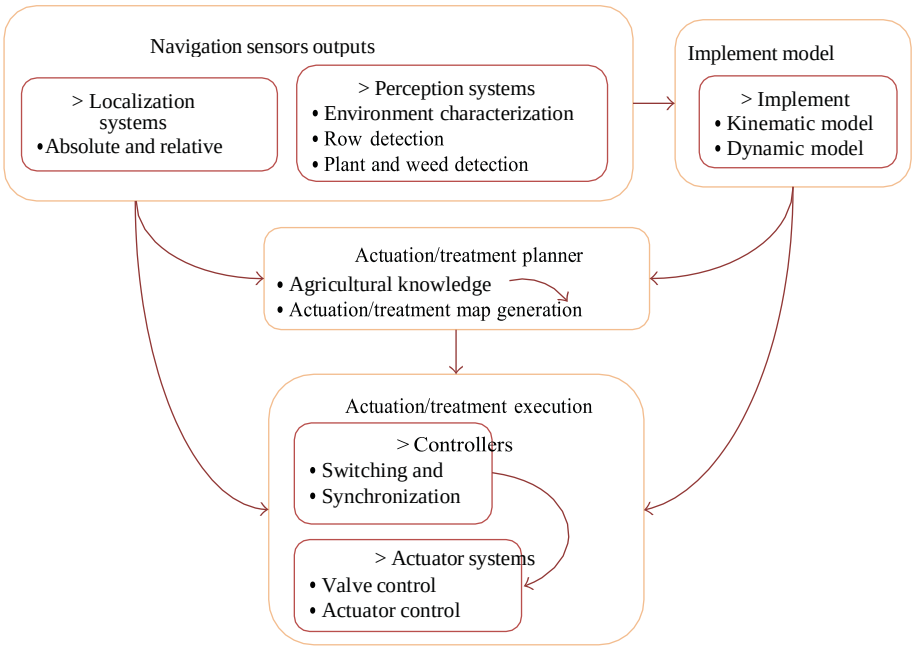
Autonomous implement framework




(b)

Figure 1: General frameworks of a fully autonomous crop operation. (a) Core components of an agricultural vehicle guidance system. (b) Fundamental elements of autonomous field implements..

The research described in this paper forms part of the RHEA project, an FP7 initiative funded by the European Commission. The primary objective of RHEA is to develop a new generation of autonomous agricultural vehicles capable of performing both chemical and mechanical crop management. The goal is to minimize the use of agricultural inputs, reduce environmental pollution, ensure better crop quality and safety, and ultimately lower production costs.

To achieve these outcomes, the project focuses on several key research areas:

(a) advanced perception technologies for assessing crop conditions, including reliable crop-row detection;

(b) innovative actuation mechanisms for precise application of fertilizers and herbicides, as well as targeted weed removal; and

(c) the creation of a fleet of compact, safe, reconfigurable, and complementary robotic units designed to operate cooperatively across entire agricultural fields.

Supporting this scientific work are additional technological developments in:

(d) robust communication and localization systems for coordinating robot fleets;

(e) improved simulation platforms and collaborative graphical user interfaces; and

(f) next-generation fuel cell solutions to provide clean, efficient power (see Figure 2).

Figure 2: The RHEA fleet (ground mobile units and implements).

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A straightforward approach to designing a fully autonomous agricultural system is to integrate the two subsystems described earlier—an autonomous vehicle and an autonomous implement—into a coordinated operational unit. Achieving this integration requires a communication structure in which a Main Controller combines the behavior of both subsystems into a unified control strategy, allowing the entire system to function as a single robotic entity. In this configuration, the autonomous agricultural system can be organized into three primary modules: the vehicle, the implement, and the controller.

**The Vehicle:** The vehicle module is responsible for managing the motion of the implement, ensuring that its position and orientation are accurately controlled according to the type of crop and the specific agricultural operation being performed. Since the vehicle typically carries or tows the implement, it also supplies the necessary power, which makes it essential for the vehicle to include standard mechanical interfaces (e.g., three-point hitch), electrical generation systems, and hydraulic pumps.

Commercial agricultural tractors already incorporate these components, making them a practical and efficient platform for conversion into autonomous vehicles. Leveraging commercially available tractors accelerates system development by reducing the need for time-intensive tasks such as chassis construction, manual assembly, mechanical testing, and vehicle certification. This approach also improves system reliability, as key elements—such as the engine, transmission, steering, braking systems, and housing—have been extensively validated under real-world operating conditions.

Alongside these considerations, system safety, robustness, and operational efficiency remain essential factors when designing the structure of the autonomous vehicle subsystem.

The vehicle selected for the RHEA project was the CNH Boomer-3050, a 51-hp (37.3-kW), 1200-kg compact agricultural tractor. Its modified cabin, cleared of all original interior components, served as the housing for the onboard computing systems responsible for perception, communication, localization, safety, and actuation. Several external components—such as the vision cameras, laser sensors, GPS antennas, communication antennas, and emergency stop buttons—were mounted outside the cabin to ensure proper operation. The complete system is organized into the following subsystems:

- **Weed Detection System:** A machine-vision–based module designed to identify weed patches within the crop field.
- **Crop Row Detection System:** A vision-based guidance system that assists in maintaining accurate vehicle alignment with crop rows.
- **Obstacle Detection System:** A forward-facing laser range finder used to sense obstacles in the vehicle's path.
- **Communication System:** Equipment enabling connectivity between the operator station, autonomous units, and portable devices used by field personnel.
- **Two-Antenna GPS System:** A dual-antenna setup used for precise vehicle positioning and orientation during field operations.
- **Inertial Measurement Unit (IMU):** A sensor module that supports the GPS system by providing additional motion data for improved localization accuracy.
- **Vehicle Controller:** The subsystem responsible for computing steering, throttle, clutch, and braking commands needed for accurate path tracking. These actuations are typically accessed through the vehicle's CAN bus interface.
- **Central Controller:** The main decision-making system that gathers data from all perception modules and determines the appropriate actions for the actuation subsystems.
- **Auxiliary Power Supply:** A fuel-cell-based energy unit monitored by the central controller to ensure continuous, clean, and efficient power delivery.

Figures 3(a) and 3(b) show the original CNH Boomer T3050 and its modified autonomous version, respectively. In the redesigned model, the cabin has been reduced to accommodate the embedded computing systems, while additional components—including the fuel cell, a roof-mounted solar panel, an antenna support bar, and the internal equipment layout—are clearly visible. The antenna bar and equipment distribution are further detailed in Figures 3(c) and 3(d).

**Implements:** Implements are external devices designed to perform specific crop-related actions, such as herbicide and pesticide application or mechanical and thermal weed control. Modern precision agriculture demands that these components operate independently so that treatments can be applied only where necessary. To achieve this, nozzles, burners, and other functional elements often incorporate positioning systems that enhance targeting accuracy. Programmable logic controllers (PLCs) and onboard computers are typically used to manage these components and synchronize their operation with the autonomous vehicle. Within the RHEA project, three distinct implements have been developed:

**Boom Sprayer**

The herbicide boom sprayer [23], intended for cereal crops (see Figure 4), features a 5.5-m boom equipped with 12 independently actuated nozzles spaced at 0.5-m intervals. Mounted on the vehicle, the implement carries two herbicide tanks with capacities of 200 L and 50 L, enabling mixing of different formulations. The Main Controller governs both the herbicide flow and the boom's folding/unfolding mechanism.

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**Mechanical-Thermal Weed Control Implement**

The mechanical-thermal system [25], used for flame-resistant crops such as maize, garlic, and onion (see Figure 4(b)), includes four pairs of burners mounted on a frame designed to cover four adjacent rows. The vehicle tows the implement and controls its lateral alignment relative to the vehicle's path. Burner intensity is dynamically regulated based on data from the machine-vision-based Weed Detection System, which estimates weed density as the percentage of vegetation within a standard area unit (typically 0.25 m × 0.25 m). The vehicle controller also manages the folding/unfolding system of this implement.

FIGURE 3: Description of RHEA Mobile Unit Modifications**(**a) Initial commercial tractor. (b) Final RHEA mobile unit after modifications. (c) External equipment mounted on the mobile unit. (d) Internal equipment distribution inside the mobile unit's cabin

(a) (b) (c)

Figure 4: Implements controlled by the RHEA system: (a) boom sprayer, (b) flame hoe, and (c) canopy sprayer.

**System Architecture**

For any autonomous system there are three steps (a) to make a mechanical structure (b) to build a control system (c) execution of specific work. The system architecture of the project is shown in fig. 5. It describes how the system device connected with each other physically.

Here seven ultrasonic sensors are in use. Four ultrasonic sensors are used for tracking the path and one ultrasonic sensor is used for detecting obstacle. Four DC motors are used where left side front and rear wheel are connected in same way and right side front and rear wheel are connected in same way to the NodeMCU as shown in block diagram. All sensors are connected with microcontroller as input component which gives the environmental data and other like motor-driver is also connected to the microcontroller as output which navigates the wheel according to requirement.

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Every connection is done with input output pin of the NodeMCU board. Another two ultrasonic sensors are used in taking another row after ending of the current row. These two sensors are combined with compass sensor [14] and detect the next path to be followed. [18] There are literature on front wheel drive and rear wheel drive but in this project 4 motors are connected with four wheels for proper balancing as well as maintaining the speed of the vehicle.

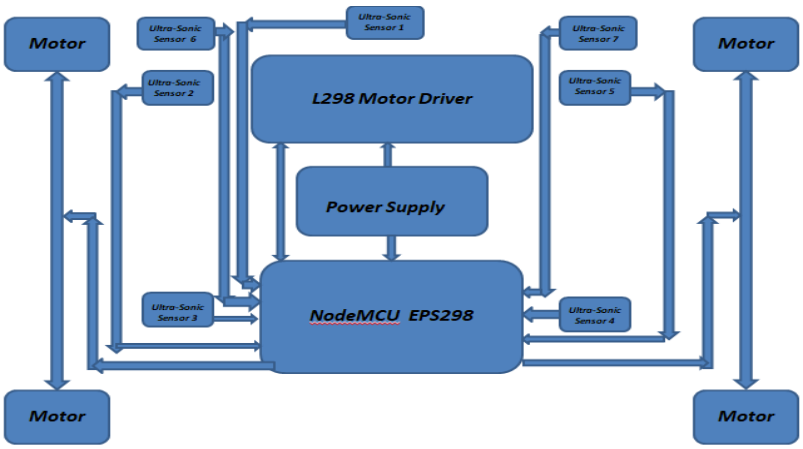


Fig. 5: System Architecture hardware

Autonomous vehicle consists of many hardware components. Some of hardware used in this project shown in figures given below:

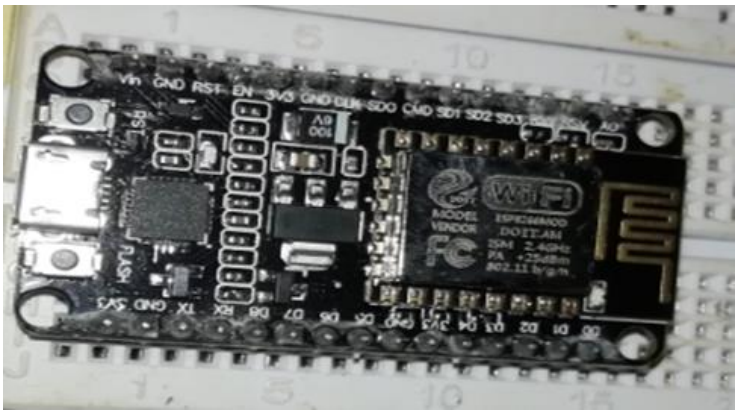

Fig.6: NodeMCU

The system has two front wheels and two rear wheel. The right side front and rear wheel are connected to the NodeMCU in same way and vice-versa. The wheels are controlled with ultrasonic sensor no. 2,3,4,5. These sensors has some threshold limit, when the value is under the threshold limit then vehicle moves straight and if both left side sensors receive greater value then it take right turn otherwise take left turn. The distances from plant are almost equal both side.

Fig. 7: Ultra-Sonic Sensor

The whole system put on the chassis which is made of lightweithed material, fibreglass of 5mm. thickness. The chassis has holes which are drilled according to the requirement. All components are put together in this chamber.

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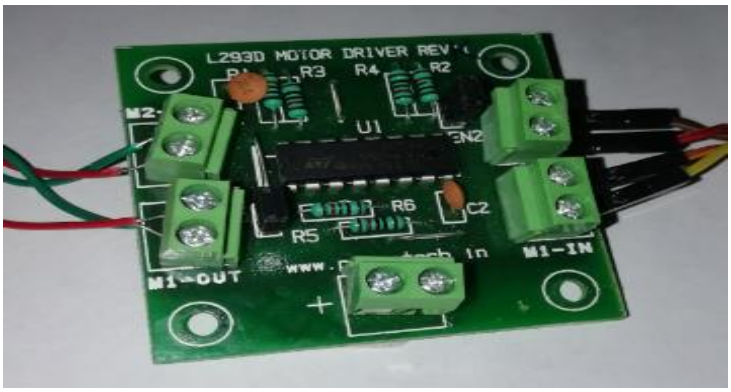


Fig. 8: Motor Driver (L293D)

NodeMCU is single board microcontroller with ESP8266, so we can perform another work too. it consists of 13 general purpose input and output pin, so any input and output device can connect with any of these 13 pins. There are many motor driver are available in the market but as we drive left side both wheel in same manner and vice-versa, we connect motor with L293D motor driver.

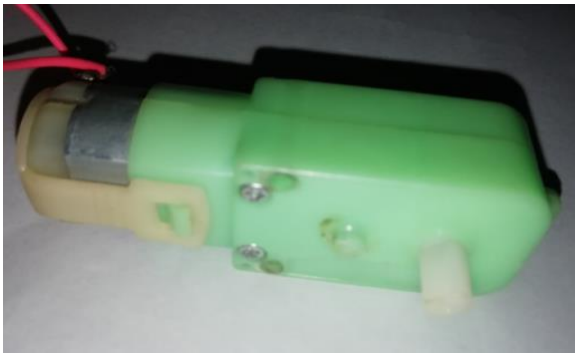

Fig.9: Geared Motor

**Front Drive:**

Two HC-SR04 ultrasonic sensors are on right side of vehicle. One is at from and another at the rear. Similarly two ultrasonic sensors are mounted on left side. When all four sensors get value under limit then vehicle moves forward. When any side of sensors get greater value then vehicle turns another side. This continues till the whole field covered. Three ultrasonic sensors are mounted in the front of the vehicle. The center ultrasonic sensor is used for detecting obstacle present in track and automatically turns back to the starting point of the row and selects another row for further motion. Another two sensors are combined with LSM303 compass sensor.

Fig.10: Wheel

**Turning action at the end of row:**

When the four ultrasonic sensors situated at the side, get greater value than threshold limit that is the sign of end of row. Then with the combined action of compass sensor and other ultrasonic sensor, vehicle take 90 degree and then move forward and backward to find the another row. Similarly it follows all rows till the end of field. Flowchart [18] for system architecture is:

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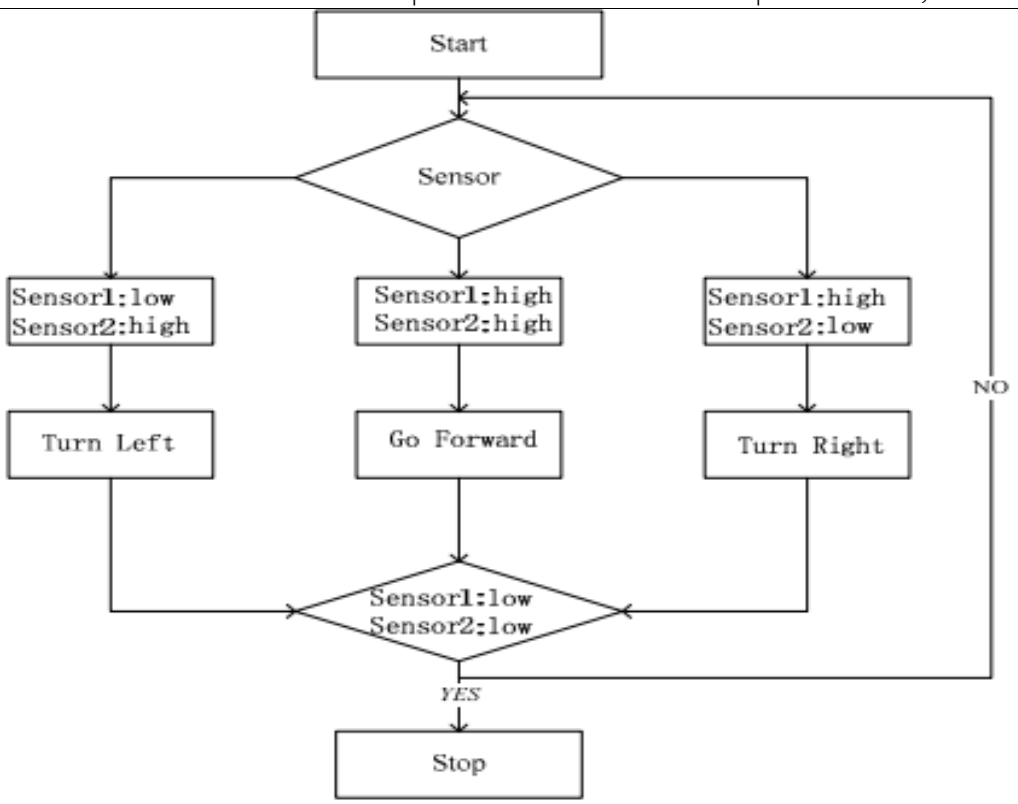


The wheel is connected with 6Volt, 0.8 Amp and 100 rpm geared motor and these motors are controlled through L293D motor driver which is programmed through Node MCU microcontroller. The programming and action of motor is totally dependent on the input data received by sensors.

## IV. Research Methodology

### Implementation Main Controller: The Evolution of the RHEAComputing System

The computing system installed on the mobile units is required to interact with several subsystems, each operating on different platforms such as Windows, Linux, and QNX. These subsystems also rely on software created in multiple programming languages, including C++, .NET, and Python. In the initial design, all these components were connected through a common Ethernet network, where a single computer functioned as the Main Controller. This controller communicated with peripheral devices using serial connections or Ethernet (802.3 LAN) through a network switch. To manage the entire communication process, a Network Manager application was also needed on the Main Controller.

As part of the system improvement, the first major step toward centralization involved incorporating the Weed Detection System (WDS) directly into the Main Controller. Since the vision camera used in the WDS complies with the GigE Vision standard—which supports high-speed video transmission—the Main Controller's dual Gigabit Ethernet ports enabled direct communication with the camera. Using Lab VIEW tools for camera configuration and data acquisition made this integration easier and removed the need for a separate vision-processing computer.

However, this integration introduced two significant challenges. The first challenge was the reuse of the original acquisition software, which had been developed in C++ for Windows 7. The second was assessing whether the Main Controller could handle the additional processing load required by the vision algorithms. The software-reuse issue was addressed through Lab VIEW's ability to interface with third-party tools, allowing external scientific libraries—such as C code, DLLs, and Code Interface Nodes (CINs)—to be called from within Lab VIEW. The strategy adopted was to convert the existing C++ vision code into a DLL so it could be directly loaded and executed on the Main Controller.

Before creating the DLL, the source code needed careful examination to identify and remove any system-specific calls, especially those dependent on Windows kernel libraries. Such calls could lead to conflicts when the code runs under Lab VIEW's Real-Time Operating System (RTOS). After adapting the code to be compatible with the RTOS environment, the necessary functions were packaged into appropriate C-based structures, following the design process originally outlined in the initial system architecture.

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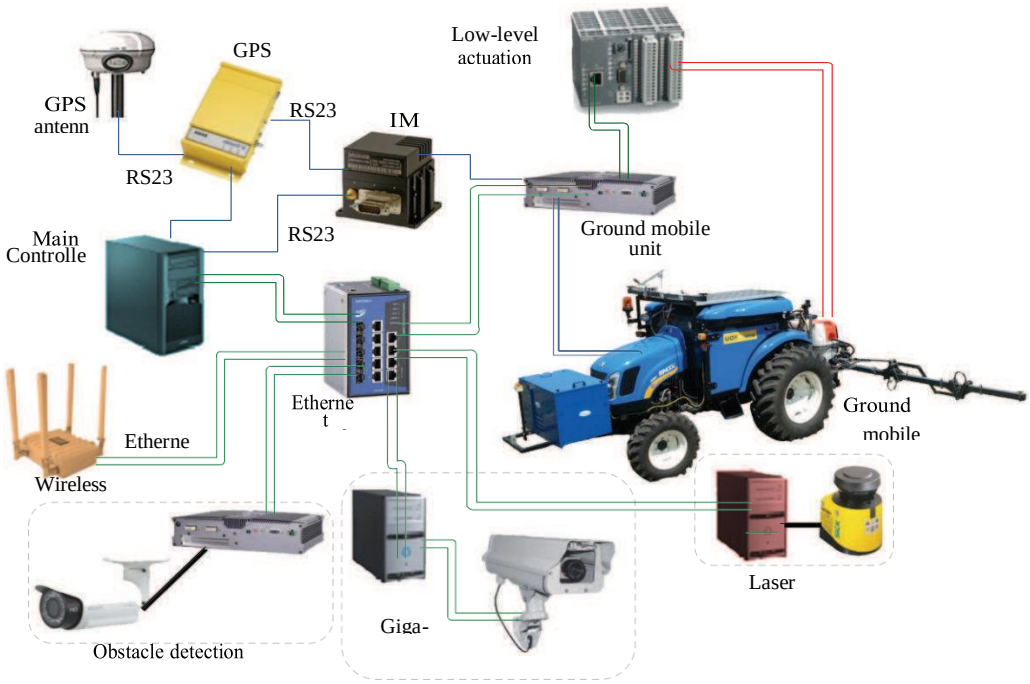


Figure 11: General schema of the fleet of robot topology for the RHEA project.

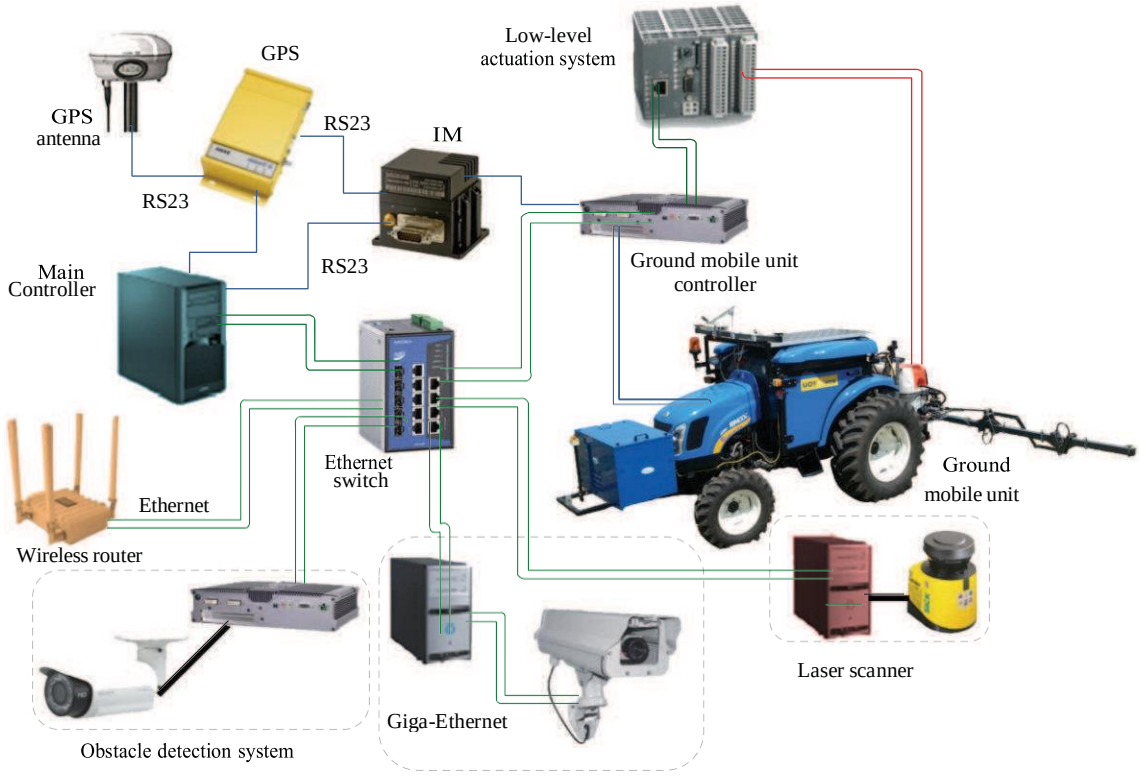


Figure 12: Overall hardware architecture designed for the autonomous mobile robot developed under the RHEA project.

The system centralization examples discussed earlier demonstrate how complex subsystems can be integrated efficiently. In addition to these, several other subsystems can be centralized more easily by leveraging plug-and-play interfaces. Technologies such as Ethernet networking via WLAN modules and switches, RS-232 communication for devices like laser sensors and inertial measurement units, CAN bus for industrial communication, ISO modules, and analog or digital I/O modules for low-level actuation make integration straightforward. The final configuration, including the main external sensing components, is depicted in Figure 10. To manage this hardware setup, a simple and structured software architecture was developed using LabVIEW. This architecture

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ensures that every subsystem connects smoothly to the main decision-making module, which handles high-level system behavior. The overall design, shown in Figure 11, is organized into three hierarchical software levels.

The first level, identified by yellow blocks, contains driver modules that handle direct communication with sensors, actuators, and other hardware components, including external user interfaces. These modules act as the bridge between physical devices and the software system.

**Used Arduino's IDE Software for controlling devices:**

This system is built using a combination of hardware and software. The hardware components are programmed and controlled through the Arduino Integrated Development Environment (IDE). Although the Arduino IDE supports C++, it does not allow the use of every feature of standard C/C++ because of hardware limitations. To simplify interaction with physical components, the Arduino environment provides ready-made helper functions and a Serial Monitor for easy input and output operations.

A microcontroller can be thought of as a compact computer embedded within a single Integrated Circuit (IC). It typically includes a CPU, RAM, ROM, and various input/output controllers—all packed into one chip. These compact devices are ideal for embedded applications such as mobile phones, game controllers, remote controls, and industrial machines, where efficient and reliable operation is required.

The term "Arduino" refers not only to the hardware but also to the company and the open-source project behind it. Arduino produces microcontroller-based development boards that are widely used in education, research, and commercial applications. Because the hardware designs are open-source, users can freely modify, customize, and build innovative projects according to their needs.

The core Arduino boards are designed with simplicity in mind. They include both analog and digital I/O pins that allow users to connect sensors, actuators, and other electronic components. As projects grow in complexity, additional expansion boards—known as "shields"—can be stacked on top of the main board. These boards also provide serial and parallel interfaces, including standard USB ports, allowing programs written on a computer to be uploaded directly to the microcontroller.

On the software side, Arduino supports programming in both C and C++. Essentially, any language that can be compiled into machine code for the microcontroller can be used. The Arduino IDE, built in Java and inspired by Processing and Wiring, offers an easy-to-use code editor with options for compiling and uploading programs at the click of a button. It also features a message area, console output, and a simple toolbar.

The Arduino IDE has its own programming structure and uses libraries specific to different boards. Each board may require different functions or libraries, so code must be written and uploaded accordingly. Once the code is compiled, it can be burned onto the appropriate board, enabling it to perform the required task.

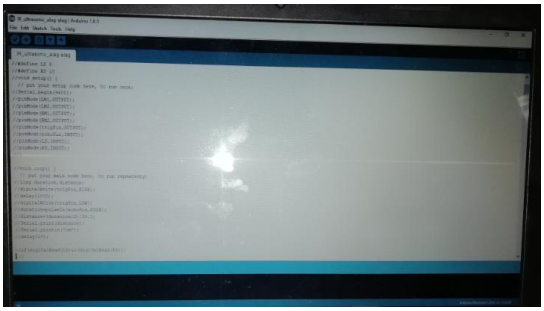

Fig.13: Arduino's IDE Screen

The Arduino IDE serves as the primary platform for developing and testing various projects using Arduino boards. It provides its own structured programming environment that allows users to write code, upload it to the hardware, and observe different performance outputs based on the programmed functions. In addition to the Arduino IDE, other software tools and applications—such as Blynk—can also be used to enhance project capabilities.

Applications like Blynk can be installed on a mobile device, enabling real-time monitoring of the operations carried out by the vehicle or hardware system. These mobile applications provide live feedback, display sensor data, and even allow remote control of the vehicle. With such tools, users can conveniently manage, track, and operate their projects directly from their smartphones, making the entire system more interactive and accessible.

## V. Conclusion

In this work, an autonomous vehicle has been developed that is capable of making decisions on its own based on the surrounding conditions. Artificial intelligence is integrated into the system so the vehicle can detect obstacles, take appropriate turns to avoid them, and then return to its original path to ensure full coverage of the field. Initial experiments were conducted in a garden to test the guidance algorithm designed for row-structured crop fields. The plants were arranged with an inner row spacing of 50 cm, and an ultrasonic sensor was used to detect plant positions and correct any lateral deviation of the vehicle.

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To demonstrate the practical implementation of a functioning autonomous fleet using the Main Controller proposed in this study, a series of evaluations were carried out in a real agricultural test field as part of the RHEA project [40]. Multiple integration and performance tests were conducted, confirming the system's efficiency and its ability to incorporate new components with minimal effort. The results are organized as follows: Sections 6.1 and 6.2 present both quantitative and qualitative findings related to the reduction of hardware components and the simplification of software development within a single autonomous agricultural platform. Section 6.3 reports the performance of a collision-avoidance algorithm, highlighting the benefits of hardware optimization for a fleet of autonomous robots designed for agricultural applications.

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