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Precision agriculture and its components

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Abstract

Even though it is one of the largest sectors of the Indian economy and has numerous inherent benefits, the agriculture industry is not doing as well as it should. We continue to engage in subsistence farming. In this research, we therefore examined precision agriculture, its application, and its constituent parts and their functions. It includes a variety of sensors, robotics, certain automated tools, the Internet of Things, and software to evaluate and start the data collection process. Precision agriculture uses the Internet of Things (IoT), which is a network of sensors, gadgets, and other objects. It has a number of sensors, including solenoidal valves, soil moisture sensors, yield monitoring, Raspberry Pi, and CO₂ and SO₂ sensors.

Keywords: IoT, sensors, CO₂, solenoidal valves, raspberry Pi

Introduction

Despite all of India's natural advantages over other nations, we still lack a lot of agricultural products (LSE, 2023) ^[7]. In India, just five states produce more than their populations can consume, while the remaining states produce less than what is needed (Sharma *et al.*, 2023) ^[9]. These states' combined populations make up less than one-third of India's total population (Sharma *et al.*, 2023) ^[9]. Over two-thirds of the population is living in a situation of food deprivation (Kaur & Dixit, 2023) ^[6].

In addition to increasing food production and contributing significantly to the nation's food security, India's Green Revolution has had some unfavourable effects (Singh *et al.*, 2020) ^[10]. Of the 328.7 million hectares of total land area, over 182 million hectares are eroded in different ways (Down to Earth, 2021) ^[3]. In contrast, India is home to 17% of the world's population, 1% of its global gross output, 4% of global carbon emissions, and a 3.6% CO₂ emission intensity (Climate Transparency, 2022). ^[2] Although the state of the environment is not particularly concerning when compared to other wealthy nations, it is imperative that these problems be addressed before they worsen. Our nation is now self-sufficient in the production of food grains thanks to the Green Revolution; in 1999, Indian farmers harvested 72 million tonnes of wheat, making it the world's second-largest producer of the grain (Sen, 2000) ^[8].

We still haven't reached the lowest level of HYV output, and the highest limit of yield in the world's agriculturally developed nations is far higher than our upper limit (Hegde & Hedge, 2003) ^[5].

Environmental problems related to agriculture, such as soil erosion and land degradation, might be interpreted as a warning against excessive use or depletion of natural resources (Breakthrough Institute, 2021) ^[1]. Because of these variables, methods and technology must be applied to farms and fields right away. All available technologies can be combined in precision agriculture to lessen land stress and boost output and productivity (UF IFAS Extension, 2020) ^[11]. Technology and data are the driving forces behind precision agriculture, which uses both to detect, analyse, and take necessary action to control a variety of field factors (GAO, 2024) ^[4].

Conventional agriculture vs precision agriculture

A variety of procedures, including site selection, land preparation, planting, intercultural activities, and harvesting, make up the agricultural process (ScienceDirect, n.d.). The primary disadvantage of traditional agriculture is that, despite our farmers' best efforts, the inputs used at each of these stages are not optimally managed; occasionally, they are in excess of what is

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needed, and other times, they are insufficient (GAO, 2022) ^[13]. This ultimately results in output that is uneven or declines. Precision agriculture enters the picture at this point. This optimizes yield and lowers financial inputs by using technology to monitor, evaluate, and determine the best moment to apply inputs (Doktar, 2024) ^[12].

Precision agriculture

Internet of Things [IoT]

People's perceptions of agriculture have changed as a result of the Internet of Things (IoT) (Mdpi, 2023) ^[18]. Precision agriculture uses IoT technologies, including robotics, GPS, and other sensors, to increase agricultural productivity and efficiency (IoT for All, 2023) ^[17]. Connecting numerous robotic devices, sensors, and actuators is beneficial for real-time monitoring and management of agricultural processes (ScienceDirect, 2024) ^[20]. The IoT facilitates the sharing of data through remote data capture based on several cloud services, enabling farmers to make informed decisions (Infopulse, 2023) ^[16]. The Internet of Things is in charge of implementing cost-effective strategies, software, hardware, and elements of smart architecture in modern agriculture (Appinventiv, 2025) ^[15].

It also assists in arranging other field activities, such as managing irrigation, planting, recording plant development, and identifying diseases, which can be made more productive and effective with the use of IoT (Spectroscopy Online, 2025) ^[21]. In order to improve the nation's agricultural industry, scientists have developed a number of affordable technologies that can be used with precision agriculture (MIT D-Lab, n.d.) ^[19].

Methodologies

A rudimentary schematic of the Internet of Things' concept and operation is shown below. The IoT system gathers, analyzes, and outputs data from several sensors and the cloud so that the farm's robots, machines, and other devices can take the proper action.

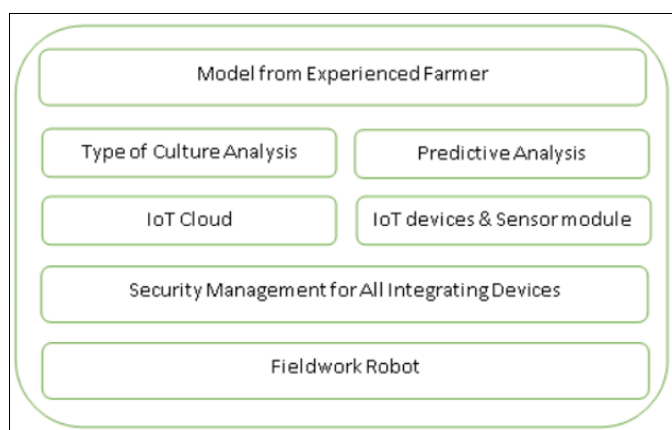


Fig 1: Block diagram of overall Proposing Concepts (Suma, 2021) ^[68].

Agricultural data analysis

The Internet of Things (IoT) system offers vast amounts of useful data that can be applied and used in various industries to improve output. In agriculture, the IoT analyzes the data and initiates the necessary actions, while the Wireless Sensor Network (WSN) collects information from the field.

The IoT assesses a number of field parameters that affect crop productivity, including soil state, atmospheric conditions, field biomass production, soil temperature, and humidity. The precise timing of irrigation, application of intercultural activities, harvesting, etc., can be determined using this WSN data, which

saves a great deal of time and resources, leading to higher output and productivity, as well as the preservation of soil health and reduced environmental risks.

Sensors used in precision agriculture

• Soil moisture meter

Many different kinds of sensors are necessary for precision agriculture to function effectively (Libelium, n.d.). An essential component of precision agriculture and the Internet of Things (IoT) are soil moisture sensors (SESITech, 2025) ^[24]. Understanding the moisture content of the soil is crucial for optimal crop growth and efficient water use (HusFarm, 2024) ^[22]. These sensors measure the soil's moisture levels and transmit the data to an IoT system for analysis and further action (Libelium, n.d.).

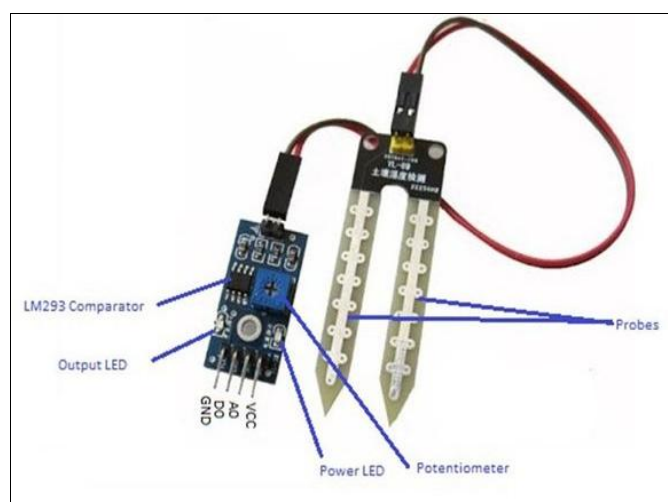


Fig 2: Soil moisture meter (Computer Engineering Department, 2022)

• Solenoidal valve:

Because it shares some characteristics with the electromagnetic properties of a solenoid, it is also referred to as an electromagnetic valve (Delco Valves, n.d.). It serves as a gate valve to regulate the flow of water in pipes, opening or closing in response to input (Maxim Systems, n.d.; Titan Fittings, n.d.).



Fig 3: Solenoidal valve (Raspberry Pi Liquid Flow Control, ResearchGate)

• Light intensity sensors

Sunlight plays a major role in agriculture (Britannica, n.d.). Plants carry out and then use the process of photosynthesis and

energy from food to carry out a variety of internal and exterior tasks (Biology Insights, 2025) [28]. They are therefore used to gauge the amount of light in fields, particularly in greenhouses and poly houses where sunlight is supplied in accordance with crop needs (IRJET, 2019) [30]. It is made up of LDR circuits that are connected to a Raspberry Pi to monitor sunlight (Pi My Life Up, 2022) [31].

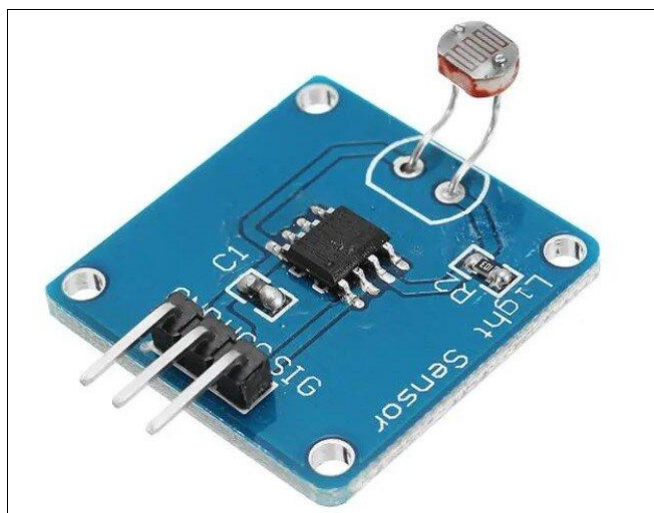


Fig 4: Light intensity sensors (Weather Monitoring System using IoT, ResearchGate)

• Raspberry Pi

All sensors are connected to this small computer board, which processes and interprets data and information from several sensors (Chip Wired, n.d.). Its processor, memory, RAM, and other connectivity requirements, such as Wi-Fi and Bluetooth, are all unique (Raspberry Pi, n.d.).

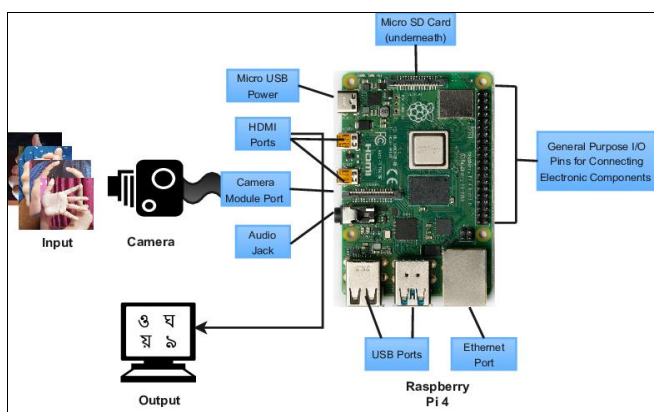


Fig 5: Overview of raspberry pi 4 implementation. (QMX-BdSL49 Implementation, ResearchGate)

• CO₂ and SO₂ sensors

These sensors are used to keep an eye on the microclimate and surroundings (sensor-networks.org, n.d.). Since SO₂ is poisonous to plants and CO₂ is crucial for their growth, it is crucial to measure their levels, which is what these sensors do (dol-sensors.com, n.d.). Precision agriculture relies heavily on this (carbondioxidedetector.com, n.d.).

Constrain in precision agriculture in India

• Coaction of different standards

Scientists are developing a variety of instruments that are utilized or have the potential to be utilized in precision

agriculture in tandem with the introduction of new technology. Interoperability and interaction between them could lead to issues. The future compatibility of the new gadgets with the current ones is not a given (abrinternationaljournal.org, n.d.).

• Training

Combining cutting-edge technologies with agriculture is known as precision agriculture. Since farmers find it exceedingly difficult to accept such technologies, the problem lies in farmer training (ijrar.org, 2020) [37].

• Connectivity issues

Internet access is either lacking or problematic in rural places. Additionally, the majority of fields are remote from civilization. Another problem with precision agricultural application is internet accessibility (vajiramandravi.com, 2024) [41].

• Data collection

Precision agriculture involves gathering data from multiple sensors and locations, which is extremely challenging to do and comprehend. It also requires a lot of training for farmers. Energy consumption and power supply: Precision agriculture requires a consistent supply of electricity to operate the sensors and gadgets used in the practice, which raises farm energy consumption (ijrar.org, 2020) [37].

• Challenges for indoor or vertical farming

Precision agriculture is a concept that was designed with outside or conventional farming in mind. Because precision agriculture is still not as significant as open or conventional farming, it has not been developed for farms that have been compacted and have introduced numerous techniques including vertical farming, hydroponics, and aeroponics (iasexpress.net, 2022) [36].

• Technical failures

The problem of technological malfunction or failure cannot be disregarded because precision agriculture is a technology-driven process with numerous electrical, mechanical, and software components. Furthermore, if there is a technical malfunction, all operations will cease, which may result in losses (ijrar.org, 2020) [37].

• Motivation

In India, a sizable portion of farmers practice subsistence farming and are unmotivated to switch. Therefore, encouraging farmers to use this technology is urgently needed in order to boost output, productivity, and minimize environmental losses (iasexpress.net, 2022) [36].

Yield monitors

A data storage device, a user interface, and a task computer situated in the combine cab that regulates the integration and interaction of these components are the main components that make up a yield monitor.

Grain, separator speed, ground speed, and grain mass or volume are all measured by the sensors (vtechworks.lib.vt.edu, 2007) [40]. Recent advancements in mass flow sensors use the idea of sending microwave energy beams and calculating the amount of energy that returns after striking the seed streams going through the chutes (precisionag.sites.clemson.edu, 2019) [38]. Devices used in fodder crops to record weights, moisture, and other data on a pre-bale basis are examples of additional yield monitoring systems (extension.missouri.edu, 1998) [35].



Fig 6: Components of the yield monitor. 1 Transport trailer, 2 Electronic and hydraulic system for arm control, 3 Implement with loading bolt for weighing fruit, 4 Standard big bags for loading fruit, 5 Electronic system for geo-referencing fruit big bags, weighing and sending data, 6 Wireless electronic system for logistic configuration and visualisation, 7 RTK GNSS antenna. (Olive Yield Monitor for Small Farms, ResearchGate)

Accurate yield data can only be obtained by calibrating a yield monitor (crops.cscience.bayer.us, n.d.). Every kind of grain harvest season requires this to be done (crops.cscience.bayer.us, n.d.). Recalibration of yield monitors should be done as needed, particularly later in the season when the average moisture content decreases or when crop conditions significantly change (crops.extension.iastate.edu, n.d.). It is typically used for weighing and documenting the moisture content of the initial loads gathered under various circumstances, including changes in operating speeds or grain flow rates (crops.cscience.bayer.us, n.d.). The yield monitor's accuracy is determined by both its design and the degree of attention to detail in the calibration process (crops.cscience.bayer.us, n.d.).

The Yield Monitor is an electrical device that requires little to no maintenance for the monitor console (extension.missouri.edu, n.d.). To make sure the sensors are in good working order, they might need to be cleaned and inspected on a regular basis (extension.missouri.edu, n.d.).

The moisture sensors in yield monitors are more likely to require cleaning in severe environments, but they can also gather debris that compromises the sensor's accuracy (extension.missouri.edu, n.d.).

Stop the combine and inspect the sensors for dirt or plant sap if the moisture or yield readings appear to alter abruptly and without any apparent cause (extension.missouri.edu, n.d.). Grain, separator speed, ground speed, and grain mass or volume are all measured by the sensors (vtechworks.lib.vt.edu, 2007) [40]. To find out whether there is an issue with the yield sensor, weigh a load of grain (extension.missouri.edu, n.d.).

Precision livestock farming (PLF)

It is described as the management of livestock production that makes use of precision agricultural technologies and ideas (Banhazi *et al.*, 2012) [44]. Animal development, milk and egg production, illness diagnosis and monitoring, and characteristics of animal behaviour and the physical environment, such as gaseous pollution discharges and the thermal microenvironment, are among the activities that are appropriate for the precision livestock farming method (Wathes *et al.*, 2008) [63]. In addition to modern robotic feeding systems, weighting systems, robotic cleaners, feed pushers, and other tools for the stockman, such as imaging systems that forbid direct animal connection, there are systems that analyse milk to check fat and microbial levels,

which can aid to flag possible infection (Berckmans, 2014) [45]. These days, there is a new system for tracking feed and water consumption data that can be utilized to identify illnesses early (Rutten *et al.*, 2013) [60]. This aids in real-time growth measurement, which is crucial for giving producers feed conversion and growth rates (Norton *et al.*, 2019) [56].

A sensor known as Acoustic is used to identify a rise in pig coughing as a sign of a respiratory ailment (Exadaktylos *et al.*, 2008) [48].

The temperature, the likelihood of childbirth, and the breaking of the waters are all monitored using a thermometer known as a vaginal thermometer, which sends an SMS to the farmer (Pastell *et al.*, 2008) [57]. An animal collar has a sensor that collects parameters to identify oestrus symptoms and the fertilizer's readiness for fertilization (Mottram, 2016) [54]. Then, an SMS message allows the farmer to plan fertilization (Tullo *et al.*, 2019) [62].

Managing individual animals through constant, real-time monitoring of their health, welfare, productivity, and environmental effect is the primary task of precision livestock farming (Wathes *et al.*, 2008) [63]. The term "continuous" in precision livestock farming refers to the PLF technology's ability to measure and analyse data every second, around-the-clock, every day of the week (Berckmans, 2014) [45]. When something goes wrong and the PLF system alerts farmers to animals that require their attention at that moment, farmers receive a warning (Norton *et al.*, 2019) [56]. The camera and real-time picture analysis, the microphone and real-time sound analysis, or the sensors on or surrounding the animal are what make the monitor function (Tullo *et al.*, 2019) [62].

Precision farming with fruits and vegetables

Machine vision techniques have recently been rapidly adopted in fruit and vegetable farming, enabling growers to grade products, monitor food safety and quality, and record factors linked to product quality automatically (Cubero *et al.*, 2011) [47]. These include the products' colour, size, form, sugar content, acidity, exterior flaws, and other internal characteristics (Blasco *et al.*, 2007) [46]. As soon as precision agriculture is used to obtain improved quality and larger yields with optimized inputs, the information may be shared with customers for risk management and food traceability to farmers (Zhang & Kovacs, 2012) [65]. According to the most recent report, new methods were developed that consider the habitat, agricultural conditions, and the actual size of the tree (Gomes & Leta, 2012) [49]. Therefore, precision agriculture is the way of the future for agriculture worldwide, not only in India (Zhang & Kovacs, 2012) [65].

Automated irrigation system with IOT based system

Use the GSM network to automate irrigation when using a rain gun system (Gutiérrez *et al.*, 2014) [51]. Researchers explained using an automated Arduino rain gun irrigation system, which saves a lot of water by only watering when there is a high demand (Prasad *et al.*, 2017) [58]. Field resource management is being altered by the use of the Android software architecture on portable devices, which contains a version of Windows, networking, and essential apps (Goap *et al.*, 2018) [50]. The tools and APIs needed to begin developing Java-based applications for the Android operating system are provided by the Android SDK (Nayyar & Puri, 2016) [55]. Mobile phones have practically become an integral part of our lives, meeting the many needs of individuals (Kim *et al.*, 2015) [53]. This application allows irrigation systems to be controlled via a cell phone's GPRS feature (Zhang & Kovacs, 2012) [65]. These systems were costly

and covered less profitable agricultural land (Huang *et al.*, 2013) [52].

The technology supports excess water levels in the soil and uses an Android app to overcome under-irrigation conditions and GSM to transmit texts (Zarco-Tejada *et al.*, 2014) [64]. Microcontroller use has been promised to extend system life and reduce power consumption due to over-irrigation, which is causing an imbalance and lowering soil nutrient content (Torres-Sánchez *et al.*, 2015) [61]. The technique is limited to automating irrigation systems and has no exceptional features (Radoglou-Grammatikis *et al.*, 2020) [59].

Why is Automatic Irrigation required?

- Efficient and simple installation and configuration (Gutiérrez *et al.*, 2014) [51].
- Conserving energy and resources to guarantee their proper and sufficient use. It avoids human error and saves time

(Prasad *et al.*, 2017) [58].

- In an automated irrigation system, valves turn the engine on and off. Motor ON and OFF can be easily automated with controls, eliminating the requirement for human labour (Goap *et al.*, 2018) [50].
- Farmers will be able to use the right amount of water at the right time in farms or nurseries thanks to computerized irrigation (Nayyar & Puri, 2016) [55].
- Reducing drainage from waterlogging saturated soils by avoiding irrigation at the wrong time of day increases crop output (Kim *et al.*, 2015) [53].
- It is an accurate irrigation instrument and a practical method for maintaining the right soil moisture level when producing highly specialized vegetable crops in greenhouses (Zhang & Kovacs, 2012) [65].

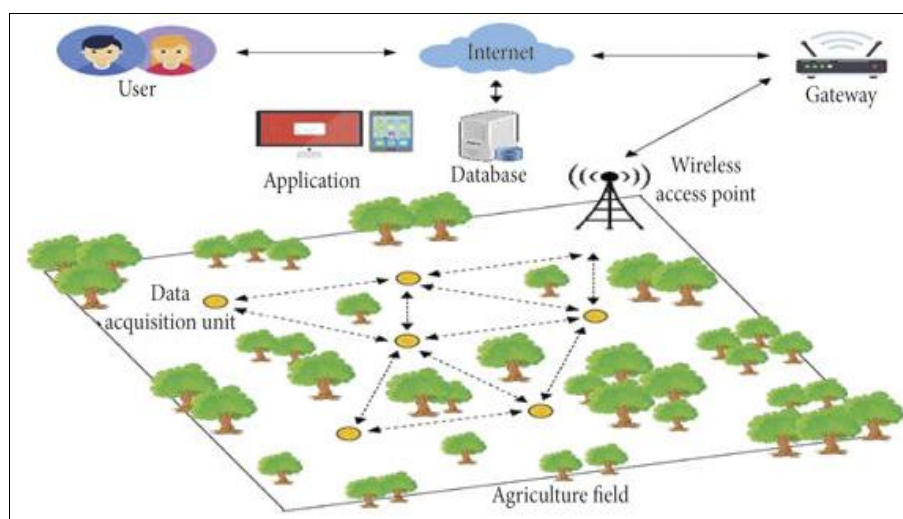


Fig 7: Wireless sensor network layout for the automated irrigation system. (IoT Irrigation Sensor Network Review, ResearchGate)

An irrigation control system that uses Android and GSM is employed to make the best use of water and resources (Huang *et al.*, 2013) [53]. In mechanical irrigation systems, valves are utilized to turn the engine on and off (Zarco-Tejada *et al.*, 2014) [64]. These valves can be easily made automatic with controllers (Torres-Sánchez *et al.*, 2015) [61]. By automating irrigation systems for their farms or nurseries, producers can deliver the right amount of water at the right time, regardless of how easily personnel can turn valves on and off (Radoglou-Grammatikis *et al.*, 2020) [59]. By ensuring that there is always adequate water and fertilizer accessible when needed, farmers who employ automated systems may see an improvement in crop yields (Banhazi *et al.*, 2012) [44]. From the standpoint of operating in a remote location, the microcontroller-based irrigation system can run continuously for an infinite length of time, even in the face of adversity (Wathes *et al.*, 2008) [63]. Advanced smartphone applications with user-friendly interfaces that are suitable for all users are lacking (Berckmans, 2014) [45]. It merely makes it possible to remotely monitor and maintain the soil water content at any time (Rutten *et al.*, 2013) [60]. When viewed from a distance, the sophisticated microcontroller-based irrigation system can function consistently for an extended period of time, even under certain unforeseen circumstances (Norton *et al.*, 2019) [56]. When crops receive the right amount of water, their yield might increase from 25% to 30% (Exadaktylos *et al.*, 2008) [48].

Microcontroller Based Automatic Plant Irrigation System

The main objective of this research project is to irrigate the crops automatically in order to save money and water resources (Pastell *et al.*, 2008) [57]. The entire system is controlled by an 8051 micro controller, which is configured to communicate the error signal to the sprinklers (Mottram, 2016) [54].

Remote Sensing and Control of an Irrigation System Using a Distributed Wireless Sensor

This article discusses a comprehensive technological configuration that is comparatively one of the most effective systems that has generated a window monitoring program for the field (Tullo *et al.*, 2019) [62]. Installing wireless communication sensors in the field expands the field area and facilitates improved assisted detector communication (Cubero *et al.*, 2011) [47]. Simple explanations of site field sensors and internet technologies are provided (Blasco *et al.*, 2007) [46]. The statistical data that was submitted is applied to this study project after being assessed for efficacy (Zhang & Kovacs, 2012) [65].

Unmanned aerial vehicle (UAV) Technology

The world's agriculture has challenges due to the growing population, which is expected to reach nine billion people by 2050 (Gomes & Leta, 2012) [49]. To effectively integrate farming, it is essential to codify state-of-the-art agricultural technologies and then adapt them to local requirements

(Gutiérrez *et al.*, 2014) ^[51].

To optimize income, preserve the environment, and promote sustainability, agricultural production systems and information technology must collaborate to recognize, evaluate, and control the critical temporal and location features of farms (Prasad *et al.*, 2017) ^[58]. To boost productivity while reducing interculture operations and fertilizer application, high fidelity is needed for micro-level application (Goap *et al.*, 2018) ^[50].

The early stages of the UAV were inspired by the military (Nayyar & Puri, 2016) ^[55]. The first UAV to take pictures for aerial surveillance in the US was a radio aircraft in 1955 (Kim *et al.*, 2015) ^[53]. As a broad reference, UAVs carried radar and television in the United States in 1941 (Zhang & Kovacs, 2012) ^[65]. Similar capabilities were created in Germany in the late 1950s, Italy in the 1960s, and Russia in the early 1970s (Huang *et al.*, 2013) ^[53]. Surveillance photos became employed during the Vietnam War, which raged from the middle of the 1960s to the middle of the 1970s (Zarco-Tejada *et al.*, 2014) ^[64]. The skills developed during this fight and soon after, civil applications, directly helped the future civil sector of UAVs (Torres-Sánchez *et al.*, 2015) ^[61]. The Condor UAV was the first to be used for forest surveying in 1986, although there were fires

in Montana (Radoglou-Grammatikis *et al.*, 2020) ^[59]. By 1994, the Predator UAV could produce images with a 30 cm resolution (Banhazi *et al.*, 2012) ^[44].

Agriculture using UAV

The agricultural production grid is composed of various elements, including soil, water, climate, weeds, pests, and their interconnections (Wathes *et al.*, 2008) ^[63]. Granularity is crucial to agriculture in order to boost output, productivity, and the efficiency of input utilization, which will ultimately lead to larger benefits with safe biological systems in the future (Berckmans, 2014) ^[45].

All of this requires comprehensive and location-specific information in order to establish a foundation of knowledge and make further decisions (Rutten *et al.*, 2013) ^[60]. Spot inspection procedures and perimeter scouting are impractical ways to achieve accuracy and precision (Norton *et al.*, 2019) ^[56]. Airborne hue and color-infrared imaging are well-researched methods for examining within-field spatiotemporal heterogeneity because the image contains depth information and may be captured at critical stages of crop development (Exadaktylos *et al.*, 2008) ^[48].

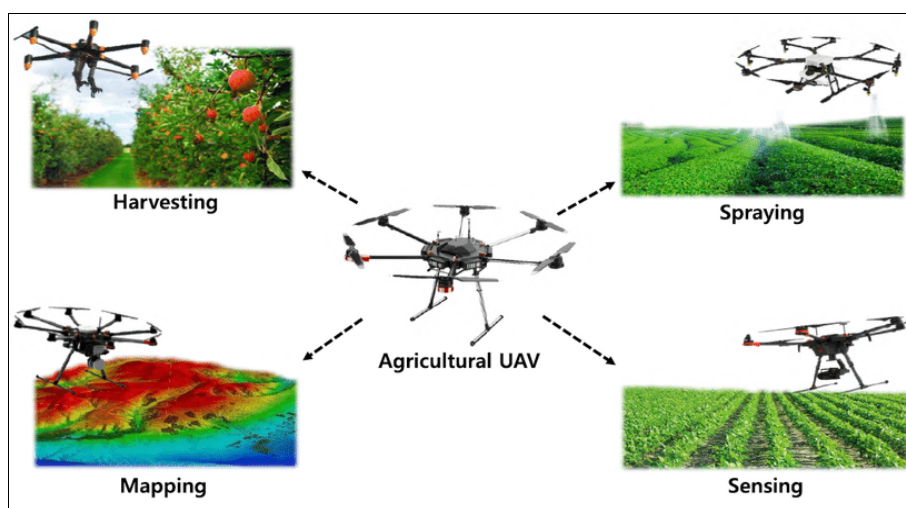


Fig 8: Different types of agricultural UAVs (Harvesting UAV, Spraying UAV, Mapping UAV, Sensing UAV. (IoT & UAV Smart Farming Review, ResearchGate)

Nonetheless, UAVs may be flown at low altitudes and can obtain more precise data with less effort if they are equipped with modern, affordable sensors (Pastell *et al.*, 2008) ^[57]. After realizing the potential of drones, the Japanese government employed them for the first time in 1986 to determine the reasons for the drop in rice growers (Mottram, 2016) ^[54]. About 35% of the pests in Japan's rice fields are managed by UAVs (Tullo *et al.*, 2019) ^[62]. The Ministry of Agriculture, Fisheries, and Forestry is currently working hard to use drones for pest control, fertilizer application, interculture, and seeding (Cubero *et al.*, 2011) ^[47]. Remote sensing techniques allow for the non-destructive monitoring of plant growth and development by utilizing the spectral reflectance and thermal emittance properties of crops and soil to their agronomic and biophysical features (Blasco *et al.*, 2007) ^[46].

Crop scouting

Unmanned aerial systems can be used to collect, process, analyse, and manage vital components of the agricultural production system (Zhang & Kovacs, 2012) ^[65].

Physical sensors like thermometers or anemometers, more

complex electronic sensors (like gas sensors, pH sensors, or hyper spectrum analysers), and optical inspection methods like Mold localization or colour estimates have all been used historically for crop scouting (Gomes & Leta, 2012) ^[49]. However, real-time data access was not feasible due to the time-consuming data collection procedures of these instruments (Gutiérrez *et al.*, 2014) ^[51].

Compared to traditional remote sensing methods, UAVs provide a number of advantages, such as the capacity to obtain incredibly high-resolution imagery below the cruising altitude with much more information at a lower initial and continuous cost (Prasad *et al.*, 2017) ^[58]. UAVs equipped with multispectral, near-infrared, visible-band, and hyperspectral scanning cameras may offer a dependable source of information for analysing crop maturity, growth, morphology, and health (Goap *et al.*, 2018) ^[50]. A crop's spectral signature can reveal if it is thriving, stressed by drought, hungry, or under attack from a virus or pest (Nayyar & Puri, 2016) ^[55]. For detecting water and nutrient stress, narrower bands work well (Kim *et al.*, 2015) ^[53]. The Photochemical Repentance Index (PRI), Water Band Index (WBI), and Normalized Pigment Chlorophyll Ratio Index

(NPCI) are a few examples (Zhang & Kovacs, 2012) [65]. Hyper spectral (i.e., repentance for numerous sequential small wavelength bands) approaches have been devised and tested with varying degrees of efficiency to identify nutrient water and pest-induced stress in plants while reducing unwanted signals from changing soil conditions or biomass levels (Huang *et al.*, 2013) [53].

Surveying and mapping using UAVs

Aerial photography can be used to quickly classify scanned areas into cultivated and non-cultivated land and assess the degree of damage caused by natural disasters (Zarco-Tejada *et al.*, 2014) [64]. Crop insurers and insurance policyholders also benefit from readily repeatable and generally available drone footage (Torres-Sánchez *et al.*, 2015) [61]. In order to more quickly and accurately calculate payments, insurance companies in India plan to use unmanned aerial vehicles (UAVs) to analyse agricultural damages following natural disasters (Radoglou-Grammatikis *et al.*, 2020) [59]. They might make a statistical graphic for risk management utilizing historical yield, weather, and pest data (Banhazi *et al.*, 2012) [44]. Insurance companies may utilize drone data to forecast and identify insect outbreaks early on and share it with farmers (Wathes *et al.*, 2008) [63].

Geo-fencing

A virtual zone or boundary known as "geo-fencing" encircles any given regional area (Berckmans, 2014) [45]. Geo-fencing is mostly used for security; whenever someone enters a geo-fenced region, the user gets texted (Rutten *et al.*, 2013) [60]. On occasion, attacks by wild animals like as elephants, birds, nilgais, mountain bulls, etc., have damaged a variety of crops (Norton *et al.*, 2019) [56]. Geo-fencing can assist in preventing these animals from attacking by alerting the landowner (Exadaktylos *et al.*, 2008) [48]. Monitoring whether an unmanned aerial vehicle crosses a certain line or escapes its range is another common use for it (Pastell *et al.*, 2008) [57]. If the UAV crosses the designated boundary, the operator receives a warning sound or a text (Mottram, 2016) [54].

Robotic agriculture

Although the world's population is growing rapidly, land and agricultural resources are remaining the same or, in some cases, declining, while governments around the world are coping with a significant increase in the demand for food resources (Tullo *et al.*, 2019) [62]. Corporate agriculture consequently started to thrive (Cubero *et al.*, 2011) [47]. The enhanced agricultural idea, which seeks to increase production and productivity while making the most of the available land, is currently used by large organizations to manage enormous swaths of land (Blasco *et al.*, 2007) [46].



Fig 9: Commercial Agricultural Robots considered in the study. (Agricultural Robotics Adoption Study, ResearchGate, Scheme 2)

Like any other business or industry, the agriculture sector is very interested in implementing robots because the production efficiency sector demands automation and the elimination of human component issues (Zhang & Kovacs, 2012) [65].

This has led to a number of scientific and technological problems, which has sparked interest in studying agricultural mobile robots or robotic farming (Gomes & Leta, 2012) [49]. Agriculture-Specific Navigation and Control the challenge of pre-programming a robot's algorithm such that it can identify its surroundings, steer clear of possible dangers, and reach its target (Gutiérrez *et al.*, 2014) [51]. This problem becomes much more challenging when a robot is working outdoors in a dynamic environment, like agricultural robots (Prasad *et al.*, 2017) [58].

Cheng, F. *et al.* used the traditional robot navigation field approach to model an apple picking and growing environment because it is simple (Goap *et al.*, 2018) [50]. Their results showed that the output of the apple-picking robot had increased (Nayyar & Puri, 2016) [55].

Yan-hong, D. *et al.* were able to address the problem of enhancing the motor servo PID controller of robot manipulators

by first identifying the drive system using a BP neural network and then refining the controller utilizing a breeding encryption method approach (Kim *et al.*, 2015) [53].

Global positioning system (GPS)

An electronic gadget called a GPS is utilized to gather data (Zhang & Kovacs, 2012) [65]. In the sphere of agriculture, GPS offers precise information in real time (Huang *et al.*, 2013) [53]. Farmers can use it to determine a specific region of the field, gather soil samples, and monitor crops on a regular basis (Zarco-Tejada *et al.*, 2014) [64]. GPS is employed in the agricultural industry for a variety of reasons (Torres-Sánchez *et al.*, 2015) [61]. For example:

- When fertilizer is applied (Radoglou-Grammatikis *et al.*, 2020) [59]
- For the planting method both inside and outside the field (Banhazi *et al.*, 2012) [44]
- When yield is mapped (Wathes *et al.*, 2008) [63]
- For the purpose of insurance, etc. (Berckmans, 2014) [45].

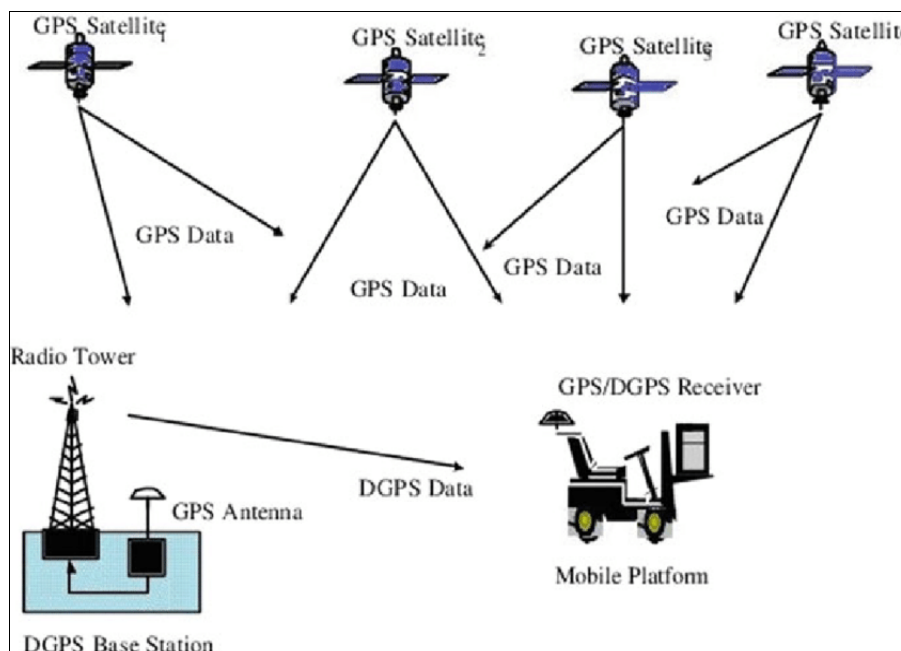


Fig 10: DGPS tower-based and satellite-based systems. (Soil Productivity Tech Review, ResearchGate)

GPS offers two primary services (Rutten *et al.*, 2013) ^[60].

- Standard positioning services, or SPS, are widely accessible to all citizens of the nation, including farmers, without any limitations (Norton *et al.*, 2019) ^[56]
- PPS (Precise Positioning System): PPS is exclusive to government organizations; civilians cannot use it with the military (Exadaktylos *et al.*, 2008) ^[48]

Geographic information system (GIS)

For the purpose of manipulating and displaying spatial data, GIS uses both hardware and software (Pastell *et al.*, 2008) ^[57]. A recent and significant development in the realm of agriculture is the geographic information system (Mottram, 2016) ^[54]. Farmers may boost their output by using GIS, which will strengthen the supply and demand chain and assist reduce damaged soil and control soil erosion and degradation (Tullo *et al.*, 2019) ^[62]. Farmers can now properly manage their soil thanks to the introduction of GIS (Cubero *et al.*, 2011) ^[47]. Farmers may maintain our environment by using GIS to apply fertilizer or disease control agents in an efficient manner (Blasco *et al.*, 2007) ^[46]. GIS has several advantages in the field of agriculture, including:

1. Yield maps (Zhang & Kovacs, 2012) ^[65]
2. Soil survey maps (Gomes & Leta, 2012) ^[49]
3. Remotely sensed data (Gutiérrez *et al.*, 2014) ^[51]
4. Report on crop scouting (Prasad *et al.*, 2017) ^[58]
5. Report on soil nutrients (Goap *et al.*, 2018) ^[50]

Grid sampling

The precision farming technique known as "grid sampling" involves dividing the field into numerous small units, collecting soil from each one, and then analysing the soil in a laboratory (Nayyar & Puri, 2016) ^[55]. and after that, we can learn about the soil's nutrient availability (Kim *et al.*, 2015) ^[53]. This approach is the most often used as it allows us to precisely determine the field's fertilizer and nutrient shortages (Zhang & Kovacs, 2012) ^[65]. Because farmers can afford the cost of the sample test, this strategy is also cost-effective for them (Huang *et al.*, 2013) ^[53]. Typically, a grid sample is taken for every two to three acres of land (Zarco-Tejada *et al.*, 2014) ^[64]. For more precision, you can

also choose a smaller area (Torres-Sánchez *et al.*, 2015) ^[61].

Conclusion

Given the massive global population growth and the fact that a significant portion of the population is experiencing food scarcity, it is imperative that we boost food production and processed food items in order to meet the demands of our people. To do this, we must also increase primary sector productivity. We can meet the agricultural requirements with the aid of the precision agriculture concept. In order to boost production and productivity at the ideal input levels, the several sensors used in PA can assist in detecting field demands like as soil moisture and fertilizer requirements.

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