Original Article

IOT IN PRECISION FARMING FOR A SUSTAINABLE FUTURE

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Abstract

Precision farming strives to improve the quality and volume of the agricultural yield with the use of modern technology. Internet of Things (IoT) can radically improve farm management with the assistance of a network of sensors, data handling systems, decision making software and remote control of farm appliances. IoT can not only help provide tailored solutions for specific farm requirements, but also allows for the optimal use of water along with the minimal use of chemicals on the crop. The natural disasters affecting the field can be predicted well in advance and the precautionary measures can be taken to protect the crop from damage. The use of IoT automates the entire process of agriculture with negligible human intervention. IoT can be applied to every phase of precision farming leading to a sustainable way of fulfilling the world's food and fabric requirements. Although the capital investment and maintenance expenses involved in precision farming are high, they can be easily recovered by the improvement in profits within a very short period of time. Government initiatives to promote precision farming will propel more farmers to adopt this technologically advanced mode of farming to obtain greater yields and improved quality produce in an environmentally sustainable manner. Key Words: Precision Agriculture, IoT, Machine Learning, Agricultural Robots, GIS.

1. Introduction

The world population is growing at a rate of 1.05% per annum which apparently necessitates the increase in food production (Dániel Fróna, János Szenderák and Mónika Harangi-Rákos 2019). Agriculture is undeniably the strongest influencer of global economy. 67% of the world's populace is involved in agriculture and it accounts for 39.4% of the GDP (Neha Khanna and Praveen Solanki 2014). The Precision Farming Market has been valued at 5147.6 million USD in 2020 and is estimated to reach 10491.45 million USD by 2026. Unfortunately, the growth driven by agriculture and improvement in economic status is hampered by natural disasters, climatic changes, pests and avian intruders. The food safety is jeopardised due to the indiscriminate use of synthetic pesticides and fertilizers, threatening the lives of the farmers, the health of the consumers and the planet at large by generating unsustainably high levels of land, water and air pollution. On an average, one third of the agricultural produce is wasted in the form of post harvest loss. Therefore, the primary challenge of agricultural scientists is to increase the quantity of agricultural produce without causing a stress on the environment and maintaining a good soil ecosystem. Addressing the loss of food in the pre-harvest, harvest and post-harvest phases is vital to enhance food and nutrition safety in an environmentally sustainable way (Patricia Müller and Markus Schmid January 2019). Precision farming aims to address each of these significant concerns with the insightful use of modern technologies. The availability, accessibility, compatibility and simplicity of use offer multiple advantages of using microcontrollers for measurement and control. Internet of Things (IoT) integrates the microcontrollers with sensors and auxiliary components. IoT converges multiple technologies, artificial intelligence, real-time analytics, sensors with embedded systems for automation of farm equipment. It offers the additional advantage of privacy and security of information. IoT can be applied with positive results for automation of greenhouses, monitoring of climate, crop and cattle.

Precision farming is an intuitive concept of farm operation and management which employs the state of the art technologies like telecommunications, robotics, satellite imaging, drones, Internet of things, microcontrollers and a wide array of sensors. It is a precise farm and crop specific approach which optimizes the utility of the farm inputs and generates greater yields, cuts down the losses and produces a superior quality crop as compared to traditional farming methods. The economic policy-making process has evolved in the recent years to include provisions for Precision farming. Precision farming has been identified as a thrust area by the United States Knowledge Initiative on Agriculture (KIA). Internet of Things (IoT) is applied to precision farming for providing customized farming solutions with the use of real time sensors and softwares to collect, organize, process, analyse, manipulate and store agricultural and environmental data and share it with various farming appliances and systems over the internet. Tailored solutions to farming can be made possible with IoT and variable rate fertilizer and pesticide applicators can be autonomously operated to achieve optimal use nutrients and chemicals on the crop (Carvalho 2017). IoT is a smart system with an approach to integrate all the agricultural operations from sensing to acting to optimize performance and quality of produce. IoT can collect data on soil nutrition, temperature, humidity, wind direction and speed, crop growth, crop yield, extent of pest infestation and weed growth to name a few. IoT provides the farmers with the convenience to remotely monitor the soil and environmental parameters as well as control the farm appliances (B.S.Blackmore, S.Fountas, L.Tang and H.Have 2004). The collected data can be processed to analyse the crop situation and consequently take informed decisions on the course of action to reduce loss and improve the quality and quantity of the produce with minimal human intervention.

2. Applications of IoT in Precision Farming

IoT has the potential to provide solutions to almost every traditional farming issue from soil sampling to harvesting, from disaster management to pest control and from yield estimation to post-harvest management among many others.

2.1 Soil Sampling

Soils possess inhomogeneous physical, chemical and biological characteristics, causing the soil health to be an intricate amalgamation of several macro and micronutrients, which must be carefully improved over time. Soil sampling enables the farmer to measure the soil fertility by determining the principal nutrients like nitrogen, potassium, magnesium, phosphorous, calcium, trace metals like iron and manganese as well as the humus and pH value of the soil. In traditional agriculture, it is customary to homogeneously fertilize the entire land resulting in overdosing and exposing the surface and groundwater to the chemicals in fertilizers. An excellent solution is site-specific agriculture which records the field inhomogeneities using geoeletrical, gamma ray, potentiometric pH and spectral-optical sensors for taking appropriate actions (R.Gebbers,E.Lück, M.Dabas and H.Domsch 2009), (J.V.Stafford 1988). A more accurate and sophisticated Laser-induced breakdown spectroscopy (LIBS) determines the soil elements by the application of exceedingly intense and narrow pulses of laser to the soil sample establishing the elemental composition making it possible to perform simultaneous multi-element analysis (N.B.Zorov, A.M.Popov, S.M.Zaytsev and T.A.Labutin 2015), (F.J.Fortes,J.Moros, P.Lucena, L.M.Cabalín and J.J.Laserna 2013).

2.2. Ploughing and Sowing of Seeds

Ploughing of the fields can be done by unmanned autonomous tractors integrated with satellite navigation, artificial intelligence and computer vision for obstacle detection even during darkness (B.S.Blackmore, S.Fountas, L.Tang and H.Have 2004). Digital Throttle Gear Optimizer (DTGO) can be attached to the autonomous tractor to achieve efficient fuel usage and digital slip meters protect the tractors from slipping. Agribot is an autonomous robot based on sensors and computer vision which is effective in sowing the seeds after establishing the depth of sowing and spacing between the seeds for optimal and uniform germination avoiding overlap of seeds (Kk Sharma, U.S. Singh, Pankaj Sharma, Ashish Kumar and Lalan Sharma 2015). Seed attributes are mapped to soil features using seed hybrid technologies.

2.3. Irrigation

Approximately 70% of the world's water usage is consumed by agriculture, which is one of the primary reasons for global water crisis and desertification of 168 countries by 2030 as predicted by UN Convention to Combat Desertification (UNCCD) (Gabriel Villarrubia, Juan F. De Paz, Daniel H. De La Iglesia and Javier Bajo 2017). Since excess irrigation leads to leaching of soil nutrients and water wastage, controlled irrigation methods like drip and sprinkler irrigation are preferred for their optimal water usage. Precision irrigation prevents water wastage and ensures soil moisture sufficiency by employing sensors in the fields. The farmers are notified of drought or flood forecasts to help them schedule the farming operations in the best possible way. Remote monitoring of crop is via smart phone with the assistance of IoT. Crop monitoring systems based on IoT also provide the farmers with precipitation and weather charts, based on which irrigation decisions can be taken (Emrick 22-24, March 2018). IoT based techniques such as Crop Water Stress Index (CWSI)-based irrigation management use a network of wireless sensors to collect air temperature, soil moisture and weather data which are transmitted to a processing centre with intelligent software applications for assessing water need.

2.4. Variable application of fertilizers

The three key nutrients required for overall plant growth are Nitrogen (N), Phosphorous (P) and Potassium (K). Excessive and homogenous fertilization of the fields has been a norm with traditional farming worldwide, which has not just affected the farmers financially but also led to their pulmonary and dermatological diseases like asthma, leukaemia, psoriasis or even terminal conditions like cancer. Excessive application of fertilizers unsettles the ecological balance of the environment by severely diminishing the soil quality, releasing toxins into the air and poisoning the ground water. IoT based fertilization solves these problems by precisely estimating the required quantities of soil nutrients for a given crop and soil type. Normalized Difference Vegetation Index (NDVI) uses satellite images to collect crop nutrient composition from the reflection of visible and near-infrared light from the plants. Autonomous Drones can be employed to selectively spray fertilizers at a variable rate on crop (Swati D Kale, Swati V Khandagale, Shweta S Gaikwad, Sayali S Narve and Purva V Gangal December 2015). Drones can be integrated with GPS technology to swiftly manoeuvre through tricky terrains. The universal sprayers and global nozzles spray both liquid and solid fertilizers, pesticides and herbicides. Such accurate implementation considerably enhances the fertilizer efficiency and is environmentally sustainable.

2.5. Crop disease and Pest Management

According to the estimates of Food and Agriculture Organization (FAO), 20–40% of the crop yields globally are lost every year owing to pests and diseases (Carvalho 2017). In an attempt to control such a heavy crop loss, the agricultural market is swarmed by pesticides and agrochemicals most of which are toxic and environmentally unfriendly. IoT based smart wireless sensors, drones and robots significantly slash the pesticide use by precisely spotting pests and eradicating them. Localised surge in crop temperature is a definite biomarker for the onslaught of plant disease. Thermal infrared imaging may be applied in Precision farming to monitor and assess the plant health by non invasively detecting the spatial inhomogeneities in the organic composition of the leaves. Infrared Thermography generates false colour images in which the pixel color indicates the local temperature, ascertaining the plant health and physiological stress conditions (Roselyne Ishimwe, Khaled Abubakr Ali Abutaleb and Faruk Ahmed September 2014). Multispectral imaging offers the benefit of early crop disease diagnosis with high precision, intuitive images, improved detection range and night vision. Normalized Difference Vegetation Index (NDVI) is an accurate marker of plant "greenness" or photosynthetic activity (Hossein Pourazar,Farhad

Samadzadegan and Farzaneh Dadrass Javan July 2019). Photosynthetically active foliage absorbs almost entire red light whereas dead or stressed foliage reflects most of the red light and less of near infrared light.

2.6. Yield Monitoring, Forecasting and Harvesting

Yield monitoring system analyzes the harvested yield quantity, grain mass flow and the moisture content. Crop forecasting predicts the crop yield and helps in future planning and decision making regarding the right time for crop harvesting to maximize the crop quality. Powerful scientific models for estimating crop yield like Monteith's model (W.Bastiaanssen and S.Ali 2003) which measures Photosynthetically Active Radiation, Stanford's model (J.Monteith 1972) which estimates the efficiency with which light is used and Surface Energy Balance Algorithm (Richard G. Allen; Masahiro Tasumi; and Ricardo Trezza 2007) for providing time-space variation in land wetness. IoT combines a yield monitor which is installed on a harvester with a mobile app to display live harvest data and automatically uploads to the farmer's web-based platform. These mobile apps generate high-quality yield maps and share them with agronomists.

2.7. Post Harvest Management

The past two decades have seen increased globalization of the food trade increasing the distance from farm to the consumer resulting in wastage and contamination of perishable produce during transport. Consequently, it challenging to maintain the freshness and safety of the food, minimizing the wastage and expenditure involved. Tracking food shipments can be carried out efficiently with web-based systems to store, analyze, and share data to achieve complete traceability. Pre cooling of the food before exporting can ensure longer shelf life and considerably reduce wastage and contamination. Intelligent temperature controlled precooling systems like cool bots are an excellent replacement for the refrigerators which emit environmentally harmful greenhouse gases (J.T Liberty, W.I Okonkwo and E.A Echiegu August 2013). Intelligent packaging integrates Radio Frequency Identification (RFID) systems with sensors which mimic olfactory receptors, measure temperature, humidity, pH, light exposure, etc to continuously monitor the packaging integrity and food quality (Patricia Müller and Markus Schmid January 2019).

2.8. Miscellaneous Applications of IoT in Precision Farming

Indoor Farming can be entirely automated with IoT sensors and robots, controlled through cloud for effective supervision. These automated tiny farms can produce way higher yields than conventional farms by incorporating hydroponic and vertical farming techniques with 90% less water (Muhammad E. H. Chowdhury, Amith Khandakar, Saba Ahmed, Fatima AlKhuzaei, Jalaa Hamdalla, Fahmida Haque, Mamun Bin Ibne Reaz, Ahmed Al Shafei and Nasser Al-Emadi October 2020).

Birds could be a serious nuisance to agriculture as they pillage the produce causing lofty losses to the farmer. IoT based farm equipment integrated with surveillance cameras, motion sensors, microprocessors and intelligent intruder detection algorithms can be used to drive away the pesky birds by playing pre-recorded gun shots and predatory screams or firing water cannons upon the detected birds (C. Pornpanomchai, M. Homnan, N. Pramuksan and W. Rakyindee 28 February, 2011). Early detection of farm fires is possible with the temperature and fire sensors which in turn can trigger microcontroller based fire extinguishers for spot control of fires. The events of farm fire can communicated the farmer as alarm signals via smart phone.

3. Wireless Sensors in Precision Farming

Wireless sensors play a pivotal role in obtaining the soil and environmental conditions in a field. Sensors deliver critical information related to soil, crop, environment and cattle to farmers and ranchers optimizing the various agricultural processes. Wireless sensors can be further integrated with autonomous agricultural equipment and heavy machinery via internet. The major sensors used in precision farming are given as follows

3.1. Acoustic Crop Sensors

Acoustic crop sensors offer a low-cost and speedy solution to smart farm management. They are based on the principle of emitting an ultrasonic frequency wave and the consequent absorption of the sound echo spectra to determine the geometric structure of the foliage (Q.Kong, H.Chen, Y.L.Mo and G.Song 2017). These are mounted on various farm appliances to identify and distinguish plants from soil, plants from weeds, fruits and vegetables from the rest of the foliage, harvested area from the non harvested area, pest detection and seed classification. Based on the sensor data, the equipment can be employed for soil cultivation, weeding, harvesting, pest detection and classifying the seed varieties (Vicent GassoTortajada, Alastair J. Ward, Hasib Mansur, Torben Brøchner, Claus G. Sørensen, and Ole Green 2010).

3.2. Optical Sensors

Optical Sensors make use of light reflectance phenomena to distinguish between soil organic matter, soil moisture, plants and minerals in the soil along with their composition (Pajares.G 2011). The unique spectral signature emitted by a particular reflecting object can indicate the changes in soil composition, moisture content, density, moisture in leaf and chlorophyll content helping in the process of determining the soil and plant health (Molina.I, Morillo.C, García-Meléndez.E, Guadalupe.R and Roman.MI 2011). Optical sensors based on fluorescence are applied to observe plant growth, crop yield, ripeness of fruits, etc.

3.3. Ultrasonic Distance Sensors

Ultrasonic Distance Sensors are a reliable and low cost option for measuring proximity to crop canopy for measuring crop growth, spraying pesticides and herbicides using drones, obstacles, etc. (Tomas Gómez Álvarez-Arenas, Eustaquio Gil-Pelegrin,Joao Ealo Cuello, Maria Dolores Fariñas,Domingo Sancho-Knapik, David Alejandro Collazos Burbano and Jose Javier Peguero-Pina 2016) . They are preferred for their negligible background noise at high frequencies and short wavelengths when reflected from thin glass blades (Stuart Bradley and Mathew Legg 2019). This makes them the primary choice to measure pasture coverage and grass growth. Ultrasonic sensor can be combined with a camera to detect weeds, plant height and crop coverage.

3.4. Optoelectronic Sensors

Optoelectronic sensors are capable of distinguishing plant type which is very advantageous in differentiating the crop from weeds. Combining the optoelectronic sensors with location information can map the weed distribution in the field. Optoelectronic sensors can also differentiate between foliage and soil from their reflection spectra.

3.5 Airflow Sensors

Airflow Sensors are used to measure soil air permeability. These can be applied to a particular location or can be used on the fly. It works on the principle of determining the pressure required to press a known quantity of air into the soil to a certain depth. Airflow sensor measures the soil moisture content, identifies the soil type from their unique identifying signatures (Veena. S, Poornima. S and Remya. J. V 2018).

3.6. Electrochemical Sensors

Electrochemical Sensors replace the expensive standard soil chemical analysis tests in assessing the soil chemistry to determine the soil parameters such as pH, salinity, macro and micro nutrient composition. Soil testing is important to attain optimal crop yields. The electrochemical sensors work by monitoring the rate of consumption of ions by plants which measures the demand of the plant for nutrients, indirectly determining the plant growth rate (John Brockgreitens, Dr. MinhPhuong Bui, and Dr. Abdennour Abbas 2016). Monitoring the plant ion concentrations enables farmers to device their strategies of fertilization to maximize crop production.

3.7. Electromagnetic Sensors

Electromagnetic Sensors observe the electrical conductivity and transient response of electromagnetic waves by contact or non-contact method. The electromagnetic properties of soil are dependent on soil texture, moisture content, salinity and organic matter. They are employed to measure the capability of soil particles to conduct or accumulate electrical charge making the soil a part of the electromagnetic circuit. They can also predict the soil pH, organic matter and residual nitrates.

3.8. Mechanical Sensors

Mechanical Sensors estimate the mechanical resistance of soil which is usually related to the variable level of compaction. The mechanical sensors penetrate the soil with the help of a probe and observe the force measured by strain gauges or load cells. A pressure unit assesses the mechanical resistance of the soil to determine the soil density and root water absorption which is helpful in irrigation interventions.

.9. Location Sensors

Location Sensors based on satellite navigation are a significant component of precision farming applications such as self-driving tractors, autonomous agricultural drones as well tracking farm animals. Global Positioning System (GPS) is a freely accessible satellite navigation system which is helpful in highly accurate vehicle guidance including optimal field routes without overlap.

3.10 Biosensors

Biosensors are environmentally sustainable nanoparticles, polymers and microbes used in the smart monitoring of food quality, safety and eradication of pathogens. These biosensors enhance agricultural productivity, nutrient absorption by plants and animal production (Fanen T and Olalekan A. 2014). Biosensors are essential for climate smart agriculture with a potential to acclimate the crop by building resilience to climatic changes (Ukhurebor 2020).

3.11. Remote Spectral Sensors

Remote Spectral Sensors instantaneously detect the spectral content of the reflected light from the plant leaves. Spectral sensors are compact, light, consume low power, environmentally stable and could be handheld or mounted on drones. They measure the extent of absorption each frequency component of light to determine the characteristics and health of the plant leaf. The nitrogen contained in the leaf chlorophyll can be measured by the recording the amount of blue and red lights absorbed by spectral sensor to determine the plant health.

3.12. Agricultural Weather Stations

Self-contained units comprising of a diverse collection of sensors, called Agricultural Weather Stations are placed at strategic locations in a farm. They continually collect and relay information pertaining to air and soil temperature, rainfall, wind velocity, atmospheric pressure, solar radiation, relative humidity, leaf moisture and chlorophyll. This data is wirelessly transmitted to a central data bank at programmed intervals for further analysis and consequent course of action. The Agricultural Weather Stations are preferred for their portability and affordability.

4. Challenges in Adopting Precision Agriculture

Precision agriculture apparently requires large capital investment for setting up IoT architecture and sensor network, causing a huge financial burden to the average farmer. Operating and maintaining highly advanced equipment, gathering and analysing vast quantities of data necessitates technological knowledge and training. Rural areas suffer from internet connectivity problem which is a vital component of cloud based computing in Precision farming. Mechanical breakdown of autonomous farm equipment or IoT sensor malfunction will result in severe crop damages. If the irrigation sensors fail, plants would be either underwatered or overwatered. Power outages in cold storage units will compromise food freshness and safety. The involvement of network connected technologies, data analytics and remote sensing make Precision agriculture vulnerable to cyber hacking, theft of confidential and reputation damage.

5. Government Initiatives to Promote Precision Farming

The increasing demand for food, climatic changes, advancement in smart technologies and government initiatives to enhance food production the principal factors propelling the adoption of precision farming. Competitive and non-competitive grant programs initiated by the US government, under Agriculture and Food Research Initiative (AFRI), shortlist the best Precision agriculture proposals from various institutions and organization. Governments are offering loans to farmers at reduced interest rates and easy repayment options to encourage capital investments on technologically advanced equipment and infrastructure for Precision farming. Indian government's initiative since 2016, Precision Agriculture for Development (PAD), provides access to reliable advisory information to farmers regarding Precision Agriculture, which benefitted over a million farmers by September 2020. PAD set up a two way communication between PAD personnel and farmers for dissemination of vital information and to refine the advisory content to improve the services (Pinaki Mondala and Manisha Basu June 2009). National Agricultural Innovation Project (NAIP) has sanctioned a budget of 285 million USD for innovations in agricultural technology. Presently, there are 17 Precision Farming Development Centers (PFDCs) spread all over India for training a huge number of farmers on precision farming and offer infrastructural and operational support. Private sector companies have established around 1200 'e-choupals' all over India, equipping the farmers with information on market prices, adoption of scientific practices, weather and crop disease forecasts.

6. Conclusions

The world is primarily dependent on farming for its food needs and with the availability of innovative technologies like IoT, artificial intelligence, robotics, computer vision, satellite navigation, GIS and remote sensing, the traditional farming techniques are morphing into Precision farming. Precision farming is an environmentally sustainable farm management concept which improves the quality and volume of yield with minimal human intervention. It not just significantly reduces the water consumption, carbon footprint and chemical toxicity, but also conserves water, preserves and improves soil fertility. Initiatives by the government on sensitizing the farmers to precision farming via awareness campaigns, dissemination of validated information on current market trends, training and skill development on precision farming practices can encourage more farmers to adopt this mode of farming. As the initial capital investment in precision farming is high, the Government can help the farmers with easy repayment loans and subsidized farm appliances. There are various benefits of precision farming the investments by farmer can be recovered many-fold over a short period of time. Precision farming will assist in proffering advantageous solutions for future research studies in the form of contribution to knowledge for the progress towards agricultural and environmental sustainability.

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