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Increasing food supply to support population growth through smart farming technologies

Edward T. Chen, *University of Massachusetts Lowell, edward_chen@uml.edu*

Abstract

The farming industry has existed since the beginning of civilization, and for a long time, its operational processes remained largely unchanged. However, with the rapid advancement of technology across various business sectors, agriculture has recently experienced one of its most significant transformations: smart farming. Smart farming is designed to optimize the overall farming experience by integrating advanced technologies that enable corporations to analyze data and maximize productivity without compromising the quality of goods. More and more companies are adopting smart farming techniques not only to increase output and profitability but also to align with the industry's growing emphasis on sustainability. These innovations not only improve operational efficiency but also directly address the urgent need to increase food supply in response to global population growth. By enabling more precise and productive use of resources, smart farming technologies have demonstrated the ability to increase yields and reduce waste, thus playing a critical role in feeding a growing world.

Keywords: smart farming, vertical farming, precision agriculture, IoT in agriculture, controlled environment agriculture, sustainable farming

Introduction

The agriculture industry has benefited tremendously over the years from smart farming sometimes referred to as E-agriculture. According to the Food and Agriculture Organization of the United Nations E-agriculture is defined as "a global community of practice that facilitates dialogue, information exchange and sharing of ideas related to the use of information and communication technologies (ICTs) for sustainable agriculture and rural development" (www.fao.org). The integration of agriculture and technology practices was designed to reach a more sustainable operating system that not only equipped farmers with new analytical tools for information gathering but also automated the overall labor process to increase output levels.

Smart farming is operated by using numerous technology sensors for different sectors of the farming ecosystem. Some of the sensors used in smart farming can direct positive or negative greenhouse variables like sunlight, while others can be used in the soil or even on an animal to track health and movement. These sensors and GPS technologies introduced to the agriculture industry help collect real data and store them in servers that can be analyzed with last closed-day trends or year-to-date trends. This simplifies the process by now being able to compare the data side by side to see where adjustments need to be made in real-time (Zhang & Chen, 2023).

Other forms of technology are used by deploying drones to survey the land and collect images and recordings for security and operational reasons. The technology automates the prior practice of physically going to the location simply without causing too much disruption. Autonomous practices aren't just used for flying but also integrated with operations once done by humans that are transferred to robots. The robots are now able to maneuver across a farm and spread crops more efficiently and effectively than the human process, the robots are encrypted with data that allow exact measurements to play a role in operations. These new technologies reinforce the commitment to more sustainable farming practices while also increasing productivity levels and in return bringing in more profits.

Goals of Smart Farming

Farming and agriculture are essential parts of human survival and prosperity. With the ever-increasing numbers of the population, the food supply issue is becoming more and more acute. The human population has increased from 1.5 to 6.1 billion in the last century and the growth is becoming more exponential. It is projected to reach 9.7 billion in 2050 and 10.9 billion in 2100 (Ritchie et al., 2023). This requires a tremendous increase in food supply, while focusing on goals of sustainability, decrease in cost, and increase in production.

The issue of sustainability has been addressed and accepted by major institutions and organizations. The United Nations has highlighted "Responsible Production and Consumption" as Goal 12 of the Sustainable Development Goals, to serve as a blueprint for a better future for all. While traditional farming and agriculture have traditionally relied on the increase of the area of farming and better fertilizers, smart farming brings completely new ideas to reach sustainability and avoid the fate of the Easter Islanders who racked the land that gave them life. Walter et. al. have suggested that agriculture is undergoing a fourth revolution made possible by the availability and expansion of information technology (Walter, Finger, Huber, & Buchmann, 2017). Smart farming allows us to monitor the conditions of the crops, stock, and land to make farming more sustainable. Locally, it is especially pertinent in arid regions where soil salinity can decrease productivity and ultimately lead to desertification making it unusable for many years to come (Mohamed et al., 2021). Globally, agriculture contributes 19-29% of total greenhouse emissions. Without a strategy for reduction, ensuing climate change may require a complete change of specific crops and livestock.

Another major goal of smart farming is cost decrease. Cost efficiency can come from different sources. A network of site-specific weather data, soil mapping, yield projections, and disease probability calls allows an increase in year-round cultivation with minimal land downtime. Even with an initial investment into the new technologies, several climate-smart agriculture strategies have been shown to decrease cost and have positive net present value (NPV) and internal rate of return (IRR) (Sain et al., 2017). Information technologies can address multiple inefficiencies of the value chain by improving transparency of service and supply delivery to farmers and customers. Successful logistics management of the supply chain made possible by IT can be essential for efficiency and high-level performance, decrease in cost, and sustainable competitive advantage (Sermuksnyte-Alesiuniene et al., 2021).

Smart farming also allows for precise soil and weather monitoring leading to optimized crop rotation in agriculture. It can increase resilience and allow for better planning when it comes to pests and diseases to improve and sustain livestock productivity. Better preparation and precise understanding, monitoring, and adjusting to the environmental conditions give opportunities for increased production in farming.

Technologies in Smart Farming

The Internet of Things was first mentioned in 1998. It is a network of intelligent interconnected devices able to communicate with each other and generate and analyze data. The application and reporting of IoT in farming is more recent and has increased dramatically in the last decade (Navarro, Costa, & Pereira, 2020). IoT architecture in farming involves four essential layers: devices for data collection, wireless transmission networks, data processing platforms, and application interfaces (Chen & Yang, 2019). These layers collectively enable farmers to gather, transmit, analyze, and act on environmental and operational data in real-time.

Data from the perception layer (data collection devices) is delivered to the processing layer via the transport layer. It is done via a wireless sensor network (WSN) that allows wireless communication between sensor nodes and applications. WSN protocols can be characterized as short-range, cellular networks, and long-range (Fernández-Ahumada, Ramírez-Faz, Torres-Romero, & López-Luque, 2019). Short-range protocols enable communication over short distances and have a high data transmission rate and low power requirements. Cellular network protocols (GPRS, 4G, 5G) enable communication over long distances but have high power consumption. Protocols for long-range establish a lower power wide area network (LPWAN) and allow transmission over very long distances with low power consumption. They are, however, only able to transmit a few amounts of data. Therefore, there is a tradeoff between distance, power consumption, and the amount of data transmitted. That should be taken into consideration while designing IS architecture for a given agricultural project to make it cost-efficient and effective (Zhang & Chen, 2023).

The processing layer uses IoT platforms for data storage and management. Here there is an opportunity to define whether data is relevant for the business requirement and where it should be stored. The total goal is to store a large amount of diverse data most efficiently. Another part of processing is the data abstraction stage. Here it is finalized so the applications can use it to generate insights and outputs. Finally, the application layer provides information to farmers, as well as controls automatic processes based on the perception input. The most common applications of IoT in agriculture are chemical control, crop monitoring, disease prevention, irrigation control, soil management, supply chain management, and vehicle and machinery control (Navarro, Costa, & Pereira, 2020). These solutions can be applied to a variety of environments such as greenhouses, arable land, and orchards. Crop monitoring currently occupies the top spot in smart farming applications proving its importance. It obtains site-specific information such as temperature, soil salinity, and pH, humidity, and has been used to determine the readiness of crops of rice, maize, and alfalfa.

Combining the inputs from various types of sensors can lead to even further applications. For example, humidity, soil sensors, and weather data can be combined to optimize irrigation schedules. Visual data from plants in addition to environmental data can be used to monitor diseases and has been used in sugarcane crops. Overall, IoT in agriculture can provide exceptional ways to monitor, assess, and respond to changing conditions. The challenge remains to decide which solutions are most appropriate based on business goals and financial ability.

Artificial Intelligence
Artificial Intelligence (AI) has become a larger part of our daily lives and its integration into agriculture is no exception. As mentioned above, humanity's population has continuously been growing and in turn, is requiring either more agricultural land or more effective use of the land. AI allows farmers to create greater output from their fields with less input from their work (Talaviya, Shah, Patel, Yagnik, & Shah, 2020). In 2019, AI in agriculture was valued at around $519 million, which was projected to grow to $2.6 billion by 2025 (Munoz, 2020).

Starting from the ground up, farmers need to know what crops to plant to produce optimal yields. AI can be used in soil and weather analysis to recommend the seed to use for their land (Talaviya et al., 2020). This can be coupled with AI’s ability to predict pest invasion, soil erosion, or weather changes that may harm the crops while they are growing (Munoz, 2020). This may lead to a higher yield with a reduced chance for plant disease, allowing a maximal return on the crops the farmer produces.

With the assistance of autonomous UAVs or Unmanned ethereal frameworks (UAS), there is the potential for increased ease of crop monitoring, irrigation equipment monitoring, weed identification, herd, and wildlife monitoring, and disaster management (Talaviya et al., 2020). This leads to the ability to scan a field and find the problem while it is still in infancy, such as a small patch of diseased crops, and deal with the problem before it grows. Then these UAS or automatons may be used in crop harvesting, such as recognizing a fruit that is ready to be picked or a plant that needs to be trimmed (Munoz, 2020). Further down the line, we may be able to use AI towards robots that can determine what crop is ready at the peak timing and harvest it then.

Big Data

Technology has shown major growth over the past decade and has expanded in numerous fields of work. The implementation of big data in the farming industry has changed for the better, making huge strides towards a sustainable operating system. Big data now offers farmers the ability to efficiently monitor greenhouse levels as well as the overall health of livestock. These new technological advances help better equip farmers to ensure they are efficient and effective in their operations while also maintaining long-term sustainability.

CropX is a company that has infiltrated the agriculture industry with its state-of-the-art technology that is helping farmers analyze data to reduce water and fertilizer use on their crops. Most recently PepsiCo has contracted the firm to implement their data analytics to ensure their farmers in Mexico are on track to reduce water use by 15% by the year 2025 according to Servando Valdez who serves as PepsiCo's Director of agriculture. CropX implements trackers into the soil which send the accumulated data to the servers to analyze vs. the prior year (CropX, 2021). The data can be broken down and now allows the farmers to have real data to ensure efficiency levels are being maximized. The new age farmer now has real-time data that allows them to know exactly what is going on to not only save water but increase productivity by using the data and adapting the current methods to ensure success.

Another way data has been introduced to improve the farming industry is livestock management and tracking to improve the health and well-being of livestock. Data now can collected from livestock eating habits to miles walked in a day. In the days before big data entered the farming industry farmers had no way of identifying the issues with their livestock, but now technology can pinpoint the exact cause for certain underlying issues.

The disease is a big issue in the farming industry of animals getting sick and transmitting it to others and the only way of identifying it before was either death or a health checkup with the veterinarian. Now that has all changed; Big data can now collect blood and track these patterns that are saving farmers time by not having to track each animal down but now can access information on the cloud and compare it vs other levels and animals. Big data has made a lot of farmers' day-to-day operations easier but it has also introduced new issues for the industry. One of the biggest issues with big data is the potential for bandwidth and network outages. An example is if the farmer doesn't have the best Wi-Fi signal the data could slow or even worse false. This new reliance on the data could lead to false information being interpreted which leads to false actions taken by the farmer to correct the issue. Another big issue is the potential of blackouts, if the system goes down then the farmer no longer has access to any of the information needed to complete a day's operations.

Overall, the introduction of big data and the integration with the farming industry has changed the game in a big way. The previous practices of manually identifying and tracking this information have been able to make technological advances to improve the overall operation and track with real-time data. The practice of turning on and off a watering system has gone extinct and the use of machine learning combined with big data now gives farmers the ability to know exactly how much water each crop needs to grow fully. Big data has now given advanced tools directly to the farmers to maximize efficiency and total output while also saving time and remaining sustainable.

Challenges to Smart Farming

Cost

When we look at the implementation of smart farming, one of the leading concerns is cost. Although it is predicted that AI alone will increase production by 30% (Talaviya et al., 2020), the initial costs pose a significant barrier to entry. Many farmers would need to go into debt to implement AI into their farming, and may not be able to afford the maintenance costs (Young, 2020). Coupling these costs with the sensors necessary for IoT ranging from $10 to more than $1000, the need for adequate network coverage, subscription costs, and necessary software it may be difficult to initially implement smart farming measures for smaller farms (Funicello-Paul, 2021). We must also look at the environmental costs of implementing smart farming. Training an AI requires a large amount of data to process, leading to emissions greater than that of the lifetime of five cars for a single AI. If this were to be expanded to a large scale, the initial introduction of smart farming would release a large number of emissions, contributing to global warming (Young, 2020). There needs to be more effort put into reducing the overall negative effects on the environment.

Adoption

For smart farming to truly be effective, the farm must have access to an internet connection and be able to have all parts of the smart farm, including sensors in the field, able to connect. This may be difficult for farms in the United States, let alone in developing countries. To truly adopt smart farming technology, an emphasis on improving infrastructure must be made (Young, 2020). This leads to another set of increased costs and may be near impossible for some farmers in developing countries where access to the internet and professionals who can explain the technology is extremely limited.

Ethics

When we look at smart farming, there are a variety of benefits that are offered. From increased yield and higher profits to being better for the environment in the long run. With the planet having an ever-growing population, there is a large need for the advances smart farming provides. With that being said, some ethical concerns arise with the advent of smart farming. With the use of AI plus automatons, there is less need for human jobs on the farms. This may lead to a reduction in the available low-skill jobs. A transition will need to be made by some for the maintenance of the machines and AI, but if the robot is more efficient and cheaper, wages may decline as human labor is seen as less valuable. This likely will be less of an issue in the United States as there is already a labor shortage for agricultural jobs, but in developing countries, this will likely have a much larger impact (Young, 2020).

With the implementation of smart farming being costly at first, there is a barrier to entry that is more likely to affect small farms than large farms. This may lead to an imbalance where large farms are using smart farming, leading to higher yields at lower costs, allowing the farm to sell their crops at lower prices. This may effectively lead to small farms losing money, as they will not be able to grow crops and sell them at the same price as the larger farms that implement smart farming.

Conclusion

In conclusion, while traditional farming has served humanity for centuries, the rapid integration of digital technologies marks a pivotal shift toward precision, sustainability, and productivity. Smart farming's potential to increase food supply—especially in the face of population growth and climate change—cannot be overstated. Policymakers should support infrastructure development and offer incentives for small-scale farmers to adopt these technologies. Future research should explore emerging technologies and track measurable impacts on crop yields, input efficiencies, and profitability. The implementation of in-soil sensors now can determine greenhouse levels that can ensure a product is getting the correct amount of sunlight and water and make adjustments to achieve full crop potential. The IoT has given farmers the ability to integrate multiple systems into one where they can collect, store, and review all data necessary to ensure their farms are reaching maximum output levels and monitoring overall operations to ensure sustainable success.

Overall, the technological advances now used in the agriculture industry have been a tremendous help but with all technology, there is always the possibility of errors from either humans or computers. The possibility of blackout or data hacks is a real threat and with time and more updated tech and security, those issues will be prevented. Smart farming is here to stay and can change the agriculture industry for the better with new updates and best practices farmers now can have real-time data to back decisions and maximize their outputs which lead to increased profits while also being mindful of the environment by having sustainability-driven practices.

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