"Sensoring" the Farm

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Smart farming is gaining attention. But research needs to continue to address the challenges that come with farming efficiency.

Seventy-five years ago, *The Farmer's Almanac* was a key predictor for when to plant and reap. Today, it is still used for longer-range planning and forecasting, however, today's newest weapon for "when to do what" on a farm during a planting season is not a book, it's sensors embedded into the land and air that provide real-time data such that plans for how to make a crop more successful emerge before and after planting.

Agricultural tools have evolved for thousands of years. The first plows were made out of forked sticks to pull through the soil. That was the predecessor to plows integrating machinery to reduce soil resistance, and now, modern-day plows utilize GPS systems, allowing for precise operations. In addition to innovative machinery, farmers today have access to many computing developments that assist with increased efficiency and improvement of agricultural productivity, precision, and predictability.

In the mid-19th century, the agriculture industry began educating farmers as the United States needed to develop reliable food supplies for the betterment of society. Accordingly, baccalaureate degrees in agriculture were launched. The first American school to offer baccalaureate degrees in agriculture was The Farmer's High School of Pennsylvania, now known as *The Pennsylvania State University*. Its first graduating class in 1861 had 13 students. In 2020, 37,721 agricultural degrees were awarded across the United States.[1]

Agriculture is now a US$1.2 trillion dollar industry.[2] In the mid-20th century during the arrival of computers, farming applications began to emerge. Today, the industry continues to advance in this area, where the Internet of Things (IoT) is the main technology that facilitates smart and precision farming. Given the labor intensiveness of this industry, it makes sense that farmers use computing power to increase precision and efficiency.[3]

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AGRICULTURAL COMPUTING

Agricultural computing innovations are assisting the industry with improving efficiency, increasing crop yield, and preserving natural resources. According to the statistics portal Statista, the IoT was the most influential agricultural technology (AgTech) innovation of 2022 and had a higher impact on the agricultural market than any other AgTechs.[4] The primary computing technologies related to the IoT are under the umbrella of smart farming, which includes precision farming technologies. Recently, agricultural researchers have created systems and frameworks to help farmers efficiently connect the numerous sensor nodes and devices that monitor soil, water, and environmental data as well as control the flow of water and fertilizer to crops.[5,6] Other researchers have created systems to optimize the use of natural resources such as water and solar power.[7] Some of the key examples of the IoT's uses in agriculture are listed in Table 1.

In the next section, we provide some examples and descriptions of these uses.

LIVESTOCK MONITORING

South African multinational mobile telecommunications company MTN, which operates in many African and Asian countries, has partnered with Aotoso Technology to provide IoT-based connected collars for cattle in the Sudanese market. Farmers use Subscriber Identity Module cards on the collar and on their cell phones to get vital information about the cattle. The information helps them develop feeding and breeding strategies. The device also monitors reproduction and lactation, which can help farmers increase their income.[8]

SOIL MONITORING

The IoT can help maintain appropriate soil moisture conditions and nutrient availability, which can help increase the effect of fertilizers. As an example, Kenya's IoT-based smart irrigation system, Illuminum Greenhouses, are powered by solar panels and sensors, which work together to create an optimal environment for crops.[9] Farmers can use their mobile phones to control key indicators such as temperature, humidity, and soil moisture. An automated watering system supplies a precise amount of water if the sensors detect that the soil is dry. The solutions are cost efficient and thus accessible for smallholder farmers.[10.]

IRRIGATION MANAGEMENT AND AUTOMATION

IoT-based irrigation systems are helping improve the availability of water for farmers. For example, Nairobi, Kenya-based solar irrigation company SunCulture provides smallholder farmers irrigation and solar pumping solutions.[11] Using SunCulture's off-grid technology, farmers can extract up to 3,000 L of water per hour from wells up to 70-m deep.[12] The system also has built-in algorithms, which study the weather to optimize performance. Based on the predicted weather patterns, SunCulture's smart machines send phone and text alerts to farmers about the appropriate irrigation timing.[13] If too much water is pumped out of the ground, pressure in the aquifer gradually decreases. To ensure that the water supply does not dry out, other IoT solutions can be used to evaluate the optimal amount of water to be pumped.

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TABLE 1. Agricultural IoT technologies.

Technology	Examples
Livestock monitoring	Livestock feeding is optimized using sensors to track behavior, health, and activity.
Soil monitoring	Moisture, nutrient, and temperature data are used to determine fertilization and watering needs.
Irrigation management and automation	Water usage is optimized.
Agricultural robots for crop harvesting	Picking and harvesting tasks are automated; aerial crop assessments are provided.
Crop monitoring (yield and health)	Using sensors, images, and artificial intelligence, these systems can detect signs of disease, pests, and harvest to optimize and predict yield. Sensors are used to collect in real time and use historical data to predict the quality of soil and crop health.
Equipment monitoring and maintenance	Sensors are used to monitor machine health, performance, fuel, and maintenance.
Security	Intrusion and theft monitoring/alert services are provided.

As noted previously, farmers, for instance, can use sensors to detect soil moisture and pump water only when needed. IoT-based irrigation systems can thus minimize water consumption.

AGRICULTURAL ROBOTS

To assist with helping with labor shortages and increasing population, robotics has been integrated into the agricultural domain in many areas to reduce some of the heavy lifting, such as picking and gathering fruit, harvesting vegetables, and dealing with weeds. In addition, drones, considered flying robots, provide aerial images that assist farmers with quick assessments of crop health. Other uses of robots in farming are greenhouses (mentioned earlier), which can provide more vegetables to urban areas.[14]

Tortuga AgTech is a farming robot system. In addition to the labor-intensive tasks, it provides a way to address challenges such as damage caused by human hands during the harvesting process. Autonomous robots have a 98% accuracy when picking fruit but do require the supervision of one individual.[15] iRobot, another farming system, has also entered the harvest-automation arena. In addition to picking and harvesting, this technology can also continue running in extremely hot weather.[16]

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CROP MONITORING

Vodacom's MyFarmWeb has tools that collect and analyze data from multiple IoT sensors across a farm, which can help to improve productivity and optimize farming practices. For instance, its ITESTLeaf feature can be used to view and compare leaf tissue based on historical data. Its precision pest-monitoring feature provides a historical analysis of pests and trends. Likewise, the MyYield feature can help analyze areas with various levels of yields and identify the underlying causes of areas with low yields. As of early 2022, MyFarmWeb was being used by 7,200 farmers in the United States, South Africa, Australia, and New Zealand.[17]

EQUIPMENT MONITORING AND MAINTENANCE

In March 2023, Indian multinational conglomerate Mahindra's AgTech arm Krish-e launched IoT-based Krish-e Smart Kit (KSK), which provides equipment owners with detailed insights about their farm equipment, such as tractors harvesters and rice transplanters. The KSK uses GPS to track and remotely monitor various parameters using a smartphone or desktop.[18] The kit can be installed on any brand of equipment, which can help improve fleet performance, reduce equipment downtime, prevent unauthorized usage, and reduce maintenance costs.[19]

SECURITY

IoT-based solutions can also help prevent theft of livestock and agricultural produce. The U.K.-based IoT solutions provider Smarter Technologies Group's cattle collars send out a signal to a livestock management dashboard every 15 min. This enables farmers to gain remote visibility of their livestock. Cattle owners can also set up specific geofences and alerts, which notify them when a livestock moves outside a designated area. The company's smart fence gate alarms can inform cattle owners when there are unauthorized cattle movements.[20] Likewise, MTN's IoT-based connected collars, discussed previously, can also help prevent cattle theft.

AGRICULTURE TECHNOLOGY AS A SERVICE

The agriculture technology-as-a-service (ATaaS) market, valued at more than US$3.4 billion, is driven by small-scale farmers and their growing demand for precision agriculture.[21] Smaller-scale farmers can use ATaaS to enhance productivity and efficiency. The industry is predicted to reach US$4.93 billion by 2028.[22] The IoT's potential to transform farming practices has been one of the key drivers of the ATaaS market.[23]

ATaaS can

- streamline operations and increase efficiency using crop monitoring, livestock monitoring, soil analysis, irrigation, crop yield, and autonomous farming machinery
- provide real-time information about crops to make informed decisions about planting, fertilizing, and pest control.

To achieve these goals, ATaaS providers integrate advanced sensors and other technologies such as remote sensing and drones in their solutions. Farmers have access to a wide range of indicators that the sensors collect and measure, which can be used for accurate crop monitoring, and take proactive actions that can help them generate the highest revenue. For instance, farmers can detect potential problems such as disease, pest infestations, and soil degradation, which can help with timely interventions.[24]

AGRICULTURE COMPUTING CHALLENGES

In general, smart farming is environmentally friendly given the improvements discussed earlier. But society needs to consider the challenges that come along with changes. For example, some research states that agricultural efficiency reduced expenses of water and pesticides, but some claim that the positive outcomes of more efficient use of machinery and irrigation systems may result in higher use of pesticides and fertilizers, which can also be a result of climate change.[25] It is a fact that climate change has

increased pests that destroy crops. The point is, the entire system needs to be considered, even when improvements are made.

To grasp this statement, one can use the analysis approach of systems thinking. Specifically, one of the systems thinking laws by Peter Senge is, "Today's problems come from yesterday's solution." For example, Brazil is the largest coffee producer but also the largest pesticide consumer.[26] The pesticides used are effective for coffee production, but not good for the ecosystem and health of the system in which it resides (this includes people). The pesticides used have contaminated some water supplies and been linked to respiratory problems, high blood pressure, cancer, and cardiovascular disease. Sustainable alternatives could be considered. Agroforestry, the practice of integrating trees, shrubs, and livestock, has been known to create benefits.[27]

Like the victory gardens encouraged in the United States after World War I and World War II to meet population demands, urban planners are looking to the public to source some of their food. For example, farmers in India are also using IoT systems to increase food production in urban areas.[28] Greenhouse technology is used as well as innovative solutions such as vertical farms (growing crops on top of each other), hydroponics (growing plants without the use of soil), aeroponics (growing plants with only water and nutrients), and aquaponics (growing plants and fish together in the same environment), are being utilized along with sensors, data collection, and a device to monitor.

As the world's population increases, so too does the need for food. However, tillable land is being turned into data centers and wind farms, while other tillable land is becoming untillable due to climate change and political conflicts. AgTech is an exciting and ever-expanding science with the potential to address these challenges. Computing plays a large role, not only from sensors and the IoT, but from computing's role in creating new fertilizers, pesticides, and seeds.

Many of the systems described in this article are used by farmers to make informed decisions to optimize the use of things like fertilizer and pesticide use and natural resources (water/fuel) to minimize environmental impact. For example, water delivery can be adjusted based on real-time weather sensor data. Controlling water usage not only preserves a natural resource but also reduces costs and improves crop yields.

Data collection (from different sensors) also can assist in predicting crop yield, reducing equipment downtime (watching equipment health), and, overall, improves efficiency in many aspects of farming.

Therefore, smarter farming is just smarter, and this topic will be gaining more attention in the immediate years.

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