Applications of sensors in agriculture research

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Introduction

Data based decision systems are improving outcomes in all industries and agriculture is no exception. The practitioners and researchers in agriculture can benefit from the timely availability of data. A large class of problems due to non-availability of the data in agriculture can be solved by utilizing sensors and associated ICT systems. Examples are early pest warning systems[1], disease identification, micro weather trends, frost prediction[2], process optimizations in climate controlled systems [3] and applying soil data to regulate water supply. This lecture note examines the variables of interest, their applicability to the agriculture problems and how sensors can help solve that.

Need for sensor data

Agriculture is affected by the environment at all stages. During production, The change of seasons determine the sowing and harvest time, the availability of nutrients in soil affect plant health, the micro weather conditions lead to disease onset and spacing of light pulses decide the size of petals in floriculture. The problem is not confined to open field agriculture but affects aquaculture, animal husbandry and related areas as well.

Post-harvest needs constant monitoring of stored produce. Potatoes sprout buds if the temperature is above 4 degrees Celsius[4]. Environment conditions should not stray from prescribed limits during storage and transport across the supply chain. The market exchange of products require grading the goods with confidence and detect traces of adulteration. The table below illustrates the data capture requirements across agriculture value chain. These are examples for illustration and by no means an exhaustive list of the data requirements.

Application area	Sensors	Benefits
Micro weather monitoring and forecast	Temperature, Humidity, Rain and Wind speed/direction, Leaf wetness	Season change tracking , Disease onset prediction, pesticide scheduling for less spraying
Soil monitoring	Soil temperature and Soil moisture	Water conservation and deal with climate change
Climate, nutrients and soil monitoring	Temperature, humidity, light, pH	Precision agriculture for targeted crops, Hydroponics
Storage monitoring	Temperature, humidity, CO2, Ethylene	Cut down on post-harvest losses
Produce Grading	Spectroscopy or chemical analysis	Identify and reward quality, remove adulteration
Pheromones detection [5]	Organic compounds	Avoid PEST attacks
Farm equipment	GPS and ON OFF data	Easy Tracking and resource utilization

Application areas

Micro weather monitoring is important for open field plantations and is one of the most well understood data capture requirements in agriculture. The micro weather data comprises of temperature, humidity, pressure, rain, wind speed, wind direction, solar radiation, evaporation, soil moisture and temperature etc.

Temperature and humidity is common across most of the requirements. The plants require a certain temperature and humidity range to thrive. The fungi and pathogens also thrive in certain environment conditions. Like, mildew worms in grapes happen in certain leaf wetness, temperature and rain conditions. open field agriculture practitioners may also need evaporation and solar radiation data. Rain and soil are also critical variables. Soil needs to be monitored at different depths. Water intensive crops need soil moisture sensors to check if the roots are getting water or not. Soil nutrients like NPK needs to be monitored to check soil health. Different soil can have different pH and thus suitability for different crops.

Temperature and humidity can be done with help of semiconductor sensors. The way to measure rain is via gauges or tipping rain buckets. Wind speed and direction sensors are analog sensors. The rate of evaporation can be monitored using an evaporation PAN. A depth sensor can be used for automatic pan depth measurements. For disease onset and prediction, four sensors, namely, Rain, Leaf wetness, temperature and humidity are critical. Leaf wetness sensors try to mimic the presence of water on leaves using conductivity or capacitive measurements.

Precision agriculture and hydroponics are another major area for continuous condition monitoring using sensors. A hydroponics farm needs to mix nutrients in certain quantities and needs to measure water pH, temperature and light conditions. Greenhouses and protected cultivation areas, that need to implement a best practices template also needs environment monitoring.

We have seen the application of sensors and what kind of data they can capture for field cultivation. The big question is, do we really need data capture using sensors? Do we not have enough data already? Here we present some facts based on government reports and what is already available in the public domain.

40 % of all bank loans in India are to farmers[6]. No one has a clue on how to quantify the risk of a failed crop. Mostly people are taking a shot in the dark. There is no integrated view of a farm with micro weather, satellite and user input. With increased pressure on land, it is imperative to develop precision agriculture and sustained agriculture practices. After green revolution, we have not seen the research benefiting the last mile. Most of our advances have been in seed and strains. Irrigation uses up to 90% of the water resources[7], however there is no concrete effort to stem that wastage. Farmers in Tamilnadu had to move from Banana to Moringa but the water wastage in other areas continue unchecked. Euro zone has banned Indian mangoes and other produces are banned because of the high pesticide content[8]. These are problems that we can solve with existing technologies.

We hope we have made sufficient case for better data capture and how the absence of it can lead to problems. Now, we turn to address the sensors itself. Are the sensors same as they were years ago? What is new and what trends are visible?

Trends in Sensors

We characterize a sensor as a device that can quantify a physical process. Like, our hands can act as a sensor and check temperature of a hot bath. Our eyes act as a sensor to distinguish two colors. Agriculture has historically relied on sensor instruments to perform measurements. The practitioners can use a thermometer to measure temperature, a wet bulb thermometer to measure humidity, meters to detect lux data and chemical analysis to do soil characterization. You have companies specializing in doing fumigation and providing charts using meters. Every agriculture institute runs an observatory and they have trained staff to perform lab measurements. A practitioner may well conclude that he has access to all the required instruments and technology. This begs the question of what constitutes a modern approach towards measurements using sensors and what kind of applications can be powered that is not possible with the status quo.

New technologies

First important factor is the sensor itself. The newer sensor manufacturing technologies have matured in recent years. Now it is possible to get a semiconductor temperature and humidity sensor that provides excellent characteristics in a small package. We have Lux sensors that are one mm across and can be integrated in a very small package. The promise of Nano technologies research is one substrate that can measure different gases on one die. Due to the boom in smartphone market and the consequent demand for sensors in a small package, many sensors are available in package, power and performance that was not possible earlier. There the trend is smaller and cheaper, leading to devices that are shrinking in size and require less power.

Imagine that you want to create a soil moisture based irrigation system. You need to measure the soil moisture at different depths and at lot of points in the field for the drip system to be effective. The current sensors have low return on investment (ROI) and thus no one even attempts to build such a system. If we had flexible inkjet printer conductivity based soil sensors instead then ROI would be justified and adoption would increase. Water intensive crops like, coconut, Banana and sugar cane can benefit from such technology, resulting in water resource conservation.

Nano technologies can help make sensors that can detect pheromones and predict the onset of PEST attack. It would be impossible to create such an automatic early warning system (EWS) without the right sensors. The table below lists options for sensors important in agriculture

Sensor	Remarks	Application area
Temperature, Humidity	Semiconductor packages can be utilized to create low power and small form factor devices.	Greenhouses, Micro weather, Animal health
Rain	Tipping bucket variety, can be interfaced to a data logger	Open field agriculture
Wind speed and direction	Analog sensors	Evaporation calculations
Leaf wetness	Conductivity measurements based	
Solar radiation / PAR		
Lux		Floriculture
Evaporation		Open field agriculture
CO_2, Ethylene	NDIR package	Warehouse / Supply chain

Soil temperature and Moisture	Thermistor for temperature measurement and capacitive measurements for moisture	Smart irrigation, open field agriculture
Soil EC and pH	Mostly chemical analysis	
Soil Nutrients (NPK)	Chemical analysis	Plant health
Insect Pheromones	MEMS sensors	

Network and sensors

Second important factor is the pervasiveness of a data network. Thirty years ago, the only way to get data from field would be in form of field logs. The creation of a networked system would be an expensive proposition. Today, we can create continuous monitoring and connected systems on a limited budget. The ability to broadcast sensor data from the field to a system that can then compute and predict results opens up possibilities that did not exist before. The advent of newer networking technologies like 5G, LORA[9] and Sigfox[10] that require less power and provide better penetration augurs well for the field.

A seed company planning[11] to study effects of temperature and humidity on growth of paddy can install modern sensors with a radio package to collect and beam data automatically. We can use GPRS networks with a SIM card and create local radio networks using citizen band radios. When Sigfox kind of networks are available, we can directly beam data from sensor devices that keep humming on supplied batteries for years.

The cost of wiring a warehouse or grain silos for continuous condition monitoring would be prohibitive. However with newer sensor and radio technologies, we can directly go wireless and start collecting data without the need to wire the place and at 1/5 of the cost. A grain silo can monitor humidity for onset of fungi and do spraying whenever the system sends an alert rather than doing it on an ad hoc basis. Post-harvest monitoring presents the best case of technology improvements in both sensors and networking to create a package that can bring down the cost of monitoring and at the same time improve performance. Whereas earlier, the only option was to put costly equipment to create a monitoring system, now practitioners can install wireless sensor nodes to create local wireless networks and start monitoring conditions without doing significant upfront investment.

System integration

Third factor is the integration of sensors into decision systems that can collect and analyze data in real time and send actionable intelligence to practitioners. Earlier, the only way to visualize data was on a computer terminal or log books and doing analysis by hand. The availability of newer sensors, the pervasiveness of networks and cheapness of computing power are heralding a future where sensor data is fed into a system that utilizes researcher input and can predict outcomes without time lag. A sensor in itself is only useful when we can collect and interpret data and take some action. A system that integrates these features for a subscriber base is providing the same impact to a large practitioners base without putting the demand of expert knowledge.

The images from a field can be transmitted directly to a smartphone and a researcher can provide input on same to a subscriber base running into millions. Doing such a system earlier would have required significant time investment and budget but is quite possible on a limited budget today.

Micro weather conditions can be collected using battery powered sensors that are relaying data constantly to a system on GPRS network[12]. The system can then crunch the numbers according to a biological or statistical model and relay predictions on potato late blight[13] or Downey mildew[14] to practitioners. The temperature, humidity and light conditions in a greenhouse can be monitored on a continuous basis and equipment can be turned on and off based on sensor input obviating the need for human intervention. A farm equipment leasing company[15] can install GPS and ON/OFF sensors in all leased equipment and can check the utilization in real time using a dashboard.

Conclusion

We hope we have shown enough interesting use cases to evoke your curiosity in knowing more about sensors and how they can be useful for the problem you are working on.

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