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REMOTE MONITORING AND CONTROL SYSTEMS IN AGRICULTURAL CROP PRODUCTION: THE ROLE OF SMART SENSING AND INNOVATIVE TECHNOLOGIES

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Abstract. This article looks at how innovative technologies can be used in the remote management of agricultural production. Drawing together the indicators studied, the authors propose an evaluation system built from two parts: the benefits of adopting these technologies, and the indicators of the innovation environment in which remote management takes place.

Keywords: remote monitoring, smart agriculture, innovative technologies, Internet of Things, sensors, digitalization, greenhouse automation, pest control, agro-industrial complex, food security.

Introduction

Around the world, digital technologies are spreading into almost every area of human activity at a fast pace, and agriculture is no exception. That is why Uzbekistan, too, has been paying particular attention to developing the digital economy in recent years. The President's decrees on the subject, along with the Cabinet of Ministers' resolution of 17 December 2021 "On measures to develop the digitalization system in the agro-industrial complex and agriculture of the Republic of Uzbekistan," set out the sector's priority tasks.

Analyses show that over a single season, a producer of agricultural goods has to make more than 40 different decisions, often within very short windows. Most of these relate to digitalization and bear directly on how efficiently production runs. By one estimate, 33 percent of the harvest is lost somewhere between planting, growing, storage and transport. Under these conditions, "smart" farming technologies matter a great deal, since they allow land, water, equipment and labor to be used sensibly.

Then there is the demographic picture. Forecasts from various research firms suggest the Earth will be home to roughly 9.6 billion people by 2050. Put simply, the population keeps growing year after year, and that puts serious pressure on agriculture. Food production would have to rise by 70% by 2050 to keep up. The calculations also have to reckon with possible shifts in the global climate, a steadily growing demand for clean water, the limited amount of arable land humanity has, and other factors nobody can predict.

One way to deal with the problem is to introduce management systems in agriculture on a wide scale. In other words, farms would use specialized software and high-tech equipment that can increase output and improve food quality. The Internet of Things in agriculture makes the industry as "smart," controllable, efficient and profitable as it can be. The core purpose of these management systems is to optimize farming processes and to distribute the resources received and used as efficiently as possible. The result is that smart farming can noticeably improve quality and raise production volumes.

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The aim of this article is to examine how smart sensing and remote monitoring technologies can be used to manage crop production, and to identify the benefits they bring and the conditions needed for their adoption. The article covers soil, weather, greenhouse, plant and pest monitoring, as well as the effectiveness of management systems in the agro-industrial complex.

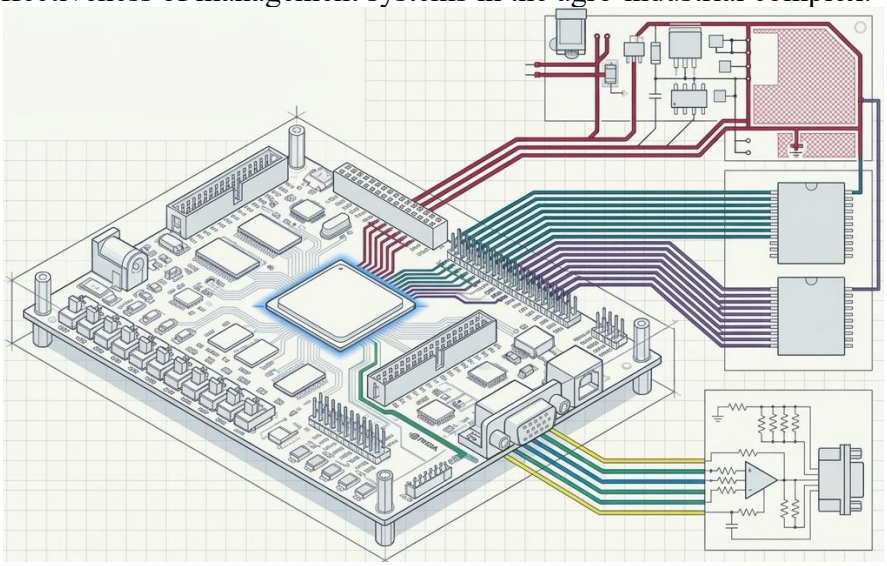


Figure 1. FPGA-based control board and its connected circuit modules (schematic view)

2. Literature Review

The digitalization of agriculture, often called smart or precision farming, is usually discussed in terms of three groups of tools: sensors that collect field data, cloud platforms that process and store it, and automated systems that act on it. Existing work and policy documents stress that these tools reduce losses, make better use of land, water and labor, and give producers faster access to market information. In Uzbekistan, the direction of this work is set by state decrees and by the Cabinet of Ministers' resolution of 17 December 2021 on digitalization in the agro-industrial complex.

3. Materials and Methods

The study is based on an analytical review of the available literature and regulatory documents, and on a systematization of the main areas in which remote monitoring is applied: soil, weather, greenhouses, plant condition and pests. The indicators identified were grouped into two parts: the benefits of adopting the technologies, and the indicators of the innovation environment in which remote management takes place. FPGA-based control schemes (Figures 1 and 2) are used as illustrative examples of how such systems are built.

4. Results and Discussion

Collecting data about crops deserves special attention, because it lets management systems run automatically and in real time. With this technology, agricultural companies can forecast the price of a given piece of farmland as accurately as possible, and they can also supply precise information about the market as a whole.

Soil monitoring. The condition of the soil is a key indicator that helps farmers decide when to sow and when to harvest. Sensors show soil moisture or salinity right away. Soil and air temperature are tracked as well, which makes it possible to schedule irrigation and to know when pests are likely to

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appear. Smart farming sensors collect the data, a cloud infrastructure processes and stores it, and the farmer can then read everything needed on a computer or smartphone.

Weather monitoring. Keeping an eye on agricultural weather is one of the main uses of such a system. Crop yields depend heavily on the environment, which by nature is unstable. Sensors installed right in the field warn of changing conditions: temperature, precipitation, humidity, solar radiation and wind speed.

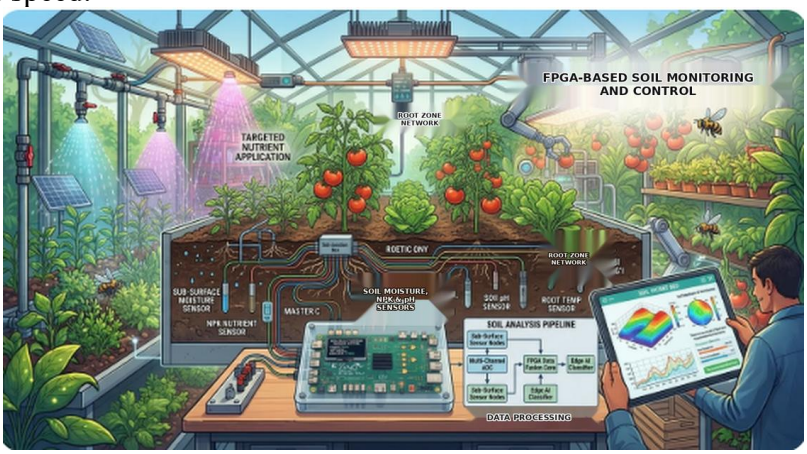


Figure 2. FPGA-based soil condition monitoring and control system in a greenhouse

Weather monitoring platforms are a clear example of how smart sensing in agriculture delivers timely alerts, on a computer or a phone, so that action can be taken when it counts.

Greenhouse automation. A greenhouse is a delicate, fragile ecosystem that needs constant care and monitoring. Smart solutions for greenhouse automation help maintain an optimal microclimate by controlling light, humidity, CO_2 levels and temperature.

Plant monitoring systems. As crops grow and ripen, plenty can go wrong. Diseases, pest infestations or unfavorable environmental conditions can do irreparable damage before farmers even notice. Smart sensing technology used for crop monitoring gathers data on the state of the plants (temperature, moisture, health indicators), so that when something goes wrong, steps can be taken in time.

Digital pest control. Without visiting the field often, it is usually impossible to know when pests appear, let alone to pinpoint their activity and location accurately. Smart agricultural monitoring systems solve these problems. They can also help work out the exact amount of chemicals needed to eliminate pests in each individual case. These pest detection systems count insects and, using cameras and sensors placed directly in the field, locate them in real time.

Effectiveness of management systems in the agro-industrial complex. By using management systems, a farm can raise its efficiency and yields, improve product quality, reduce its need for pesticides, and make its work processes more predictable and controllable. In a time of global pandemic and crisis, the agricultural sector holds great potential for keeping people employed, increasing incomes and preserving economic stability. Making good use of that potential, however, depends on innovative ideas and proposals.

5. Conclusion

To sum up, green, healthy produce grown with the latest agricultural technologies sells at a higher price. Beyond that, by collecting and reprocessing the data that smart monitoring provides,

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farmers can predict the future condition of soil and the environment and plan next year's harvest, while predictive analytics helps them make well-calculated management decisions. For fruit and vegetables, "smart warehouses" use set algorithms to track the condition of stored produce in real time (temperature, humidity, carbon dioxide levels), which supports sound decision-making. If conditions drift out of range, the system corrects the situation and notifies the warehouse owner of the change.

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