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Irrigation Automations in Digital Agriculture

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Abstract

Water is an indispensable natural resource for sustaining all living organisms, yet it is limited in quantity. Rapid population growth, climate change and the associated tendency toward drought observed worldwide are increasing the demand for water resources day by day. This growing demand places serious pressure on water resources and adversely affects agricultural production in particular. The efficient use of water in agricultural production is a decisive factor in productivity. Therefore, the integration of irrigation automation systems into agriculture has become one of the priority issues of the sector. With advancing technology, the use of artificial intelligence based solutions in agricultural irrigation is becoming increasingly widespread; these solutions optimize irrigation processes and make significant contributions to water conservation and sustainable management. In this study, irrigation automation systems implemented in Turkiye and around the world were examined in detail; the functioning of current technologies, their fields of application and the benefits they provide were evaluated from an academic perspective.

Keywords: *Digital agriculture, Irrigation automations*

Introduction

The deepening global effects of climate change and drought have made water management one of today's most critical agenda items (Boujdi et al., 2024). The sustainable management of water resources and the efficient use of existing water potential are of critical importance in addressing the global water crisis. For this reason, irrigation automation systems which are among the applications of digital agriculture, are among the core technologies that contribute to increasing resource efficiency in agricultural production by ensuring that water is used at the right time, in the right amount and in a controlled manner. Climate induced extreme events such as drought, floods, excessive temperatures and irregular precipitation patterns disrupt ecosystem balances and threaten global food security. Considering that approximately 72% of global freshwater consumption is used by the agricultural sector, agriculture is regarded as both one of the largest users in the water crisis and one of the central areas of the solution process. Current projections indicate that agricultural water demand will increase by approximately 35% by 2050. Therefore, the effective, sustainable and controlled use of agricultural water resources has become imperative.

One of the main problems limiting the effective implementation of irrigation and fertilization practices in agricultural production is the distance between agricultural lands and the living areas of farm owners. In particular when production areas are far from settlement centers, it becomes difficult to monitor irrigation processes regularly and this leads to time losses in practice. In addition, the relatively low cost of irrigation water in Turkiye appears to be one of the major factors encouraging the unconscious and excessive use of water (Süzer, 2014).

To reduce losses arising from agricultural water use and to utilize water resources more efficiently, the use of innovative irrigation technologies is becoming increasingly important. Different methods such as drip irrigation, sprinkler irrigation, pivot systems and smart irrigation technologies are used in agricultural irrigation applications. In particular, automation based irrigation systems integrated with digital agriculture applications provide higher efficiency compared with traditional irrigation methods based on human labor or manual control.

Smart irrigation automation systems can determine the plant's water needs in real time through sensors, remote control systems and data analysis technologies, allowing only the necessary amount of water to be used. This contributes both to reducing water consumption and to lowering energy and labor costs. At the same time, conducting irrigation processes in a more controlled and planned manner supports increased productivity in agricultural production and offers significant advantages for sustainable resource management (Şahin, 2022).

Today, smart irrigation solutions referred to as water management in agriculture have been developed thanks to artificial intelligence and Internet of Things (IoT) technologies. Through these technologies, the management of available resources is optimized and water consumption is significantly reduced. Smart irrigation automation systems continuously read data such as the current amount of water at the source, atmospheric temperature and soil moisture and transfer them to the software layer, enabling real time monitoring of water use. Thanks to this structure, an irrigation regime appropriate to the actual needs of the soil can be applied (Şahin, 2022).

Irrigation automation systems are automatic systems that enable the efficient irrigation of open land and agricultural areas within a specific control mechanism. Through these systems, both water savings are achieved and uniform and balanced water distribution can be provided across the entire area to be irrigated. In addition to preventing unnecessary water consumption, irrigation automation systems also offer remote control capabilities (Roltek, 2023).

This feature is not limited to contributing to the protection of water resources; it also offers significant advantages in reducing labor costs and increasing agricultural productivity. The remote access and control opportunities provided by technology save farmers time and energy, while contributing to the more planned and sustainable execution of irrigation processes (Şahin, 2022). Although the Netherlands is a country with limited surface area, it has achieved an important position in global agriculture thanks to its advanced technology oriented production policies adopted in the agricultural sector. In particular, the effective use of modern irrigation techniques, digital agriculture applications, data driven management systems and software supported production processes has significantly increased the country's agricultural productivity and export capacity.

The widespread use of sensor technologies, automation systems and digital control mechanisms in agricultural production processes in the Netherlands enables more efficient use of water and energy resources. Thanks to this Technology based approach, production costs are reduced, sustainable resource management is supported and high value-added agricultural production models are developed. Therefore, the example of the Netherlands demonstrates that digital agriculture technologies have strategic importance in terms of increasing efficiency and sustainability in agricultural production (Saygili et al., 2018). Technological transformations implemented in different sectors have also paved the way for digitalization in agriculture, enabling the spread of innovative applications. Digital tools introduced with Industry 4.0 have led to the emergence of smart agriculture applications and new technologies in production have radically transformed the agricultural approach (Gökçe et al., 2024). Industry 4.0 tools applied at all stages of production, from sowing seeds to irrigation, spraying and harvesting, provide significant advantages to the sector. The main advantages are summarized below (Hektaş, 2021):

Thanks to digital irrigation infrastructure, the producer can irrigate the field automatically at any desired time interval and with any desired flow rate. The entire system is monitored through automation software.

Sensors placed in the field measure the instantaneous soil moisture value; the system integrated with weather data prevents unnecessary irrigation and provides significant savings in electricity and water resources.

During periods of high rainfall, the system can be stopped automatically; thus, both energy savings are achieved and the natural moisture balance of the soil is preserved (Hektaş, 2021).

Basic Components of Smart Irrigation Systems

Smart irrigation systems are Technology based irrigation solutions developed to make water use in agricultural and landscape areas more efficient, controlled and sustainable. As shown in Figure 1, these systems consist of an integrated structure composed of sensors, control units, communication infrastructure, valves and sprinkler equipment, meteorological stations and data analysis software

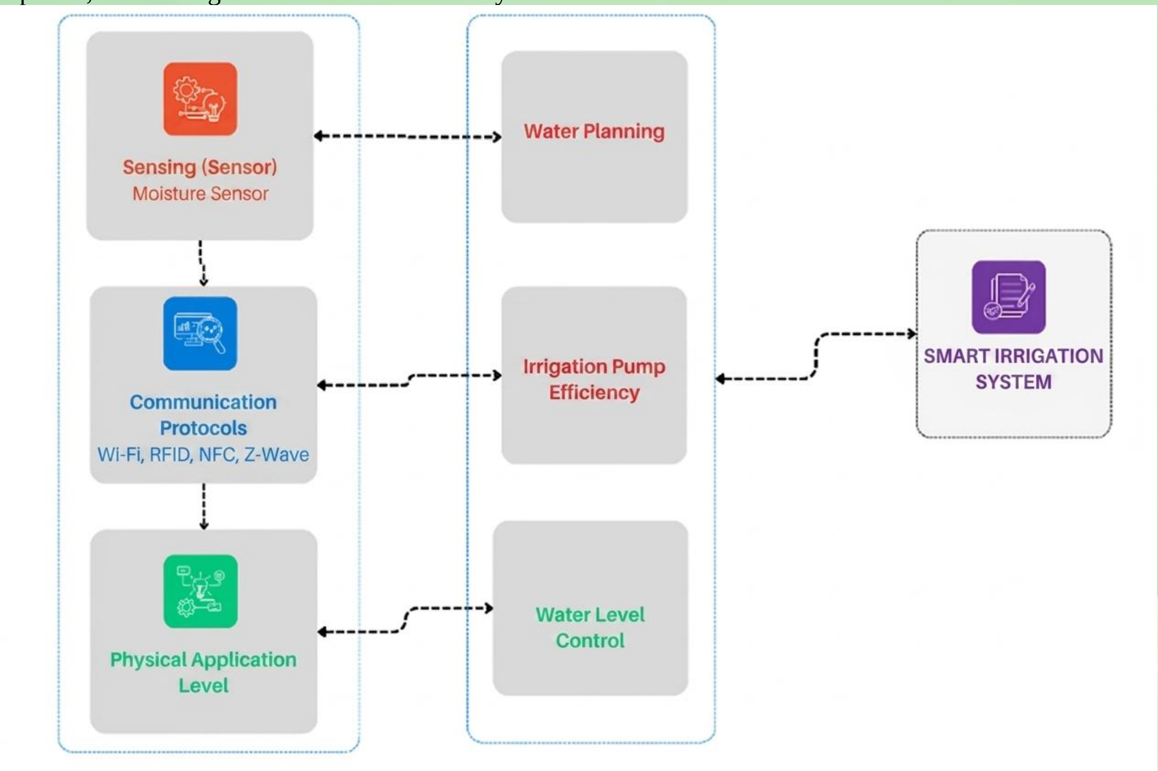

Figure 1. Basic components of smart irrigation systems (Şahin, 2022).

The sensors in the system collect real time data on the soil's moisture status and environmental conditions, while control mechanisms analyze this data to ensure that irrigation operations are carried out automatically. Smart irrigation infrastructures integrated with meteorological data determine the amount of water required by the plant and prevent unnecessary water consumption. Thus, more effective use of water resources is achieved while energy consumption and operating costs are reduced.

The coordinated operation of all these components makes important contributions to increasing water efficiency in agricultural production, protecting natural resources and supporting a sustainable production approach (Şahin, 2022).

The efficiency of irrigation systems holds critical importance in increasing food production. While the excessive and wasteful use of freshwater is usually noticed only in cases of poor management, over-irrigation often leads to the leaching of plant nutrients from the soil and the unnecessary consumption of water resources. Therefore, on-farm irrigation management systems must be precisely designed to provide the right amount of water at the right time, based on the specific water requirements determined for each crop. Consequently, through the integration of the Internet of Things (IoT) and machine learning technologies, high-precision monitoring and control systems supported by mobile and web-based applications can be developed for agricultural irrigation processes; thereby achieving significant savings in water, energy, and labor utilization (Abioye et al., 2022)

Findings

Smart irrigation systems basically consist of a smart water valve, sensors, controllers, communication systems and valves and sprinkler elements. Within the scope of this study, the functioning, hardware structure and role of each component in irrigation automation were evaluated under separate headings.

Smart Water Valve

Among smart water technologies, smart water valves stand out by enabling the remote monitoring of irrigation status and water consumption through proportional irrigation principles integrated with irrigation methods and by allowing the system to be managed through a central structure. From a hardware perspective, these systems consist of four main groups: a valve controller, a flow meter, a wireless communication module and a power supply. Each component forms a functional integrity for the continuous and reliable operation of the system.

It is observed that, within the reliable operation of the system, the smart valve continuously collects data from measuring devices positioned along the irrigation lines. The obtained data are transferred in real time to cloud based software platforms via wireless communication options; thus, the amount of water consumption and irrigation status can be monitored remotely through smart end devices such as smartphones or computers and necessary interventions can be performed remotely. Continuously supervised by irrigation automation software, the system reinforces operational safety by transmitting alerts in the event of abnormal conditions (Şahin, 2022). When these features are evaluated as a whole, it becomes clear that smart water valves have evolved from being merely irrigation control tools into core devices of a data-driven decision-support mechanism related to the management of water distribution in irrigation (Şahin, 2022).

Sensors

Optimizing water use in smart irrigation systems depends on monitoring dynamic environmental parameters such as soil moisture, ambient temperature, humidity and rainfall. Real-time data obtained through strategically placed field sensors prevent both over-irrigation and water stress caused by insufficient irrigation (Şahin, 2022). Data collected from these sensors are transmitted to a cloud server using wireless communication infrastructures such as Wi-Fi, Bluetooth, or cellular networks. The central cloud server processes the raw data through specialized software and provides the main input for the system's decision-support mechanisms (Erdal & Ergüzen, 2020). In this context, the DHT22 sensor is widely preferred because it offers high reliability in temperature and humidity measurements, calibrated digital output and stable operating performance (Liu, 2013). The physical structure of the sensor is presented in Figure 2.

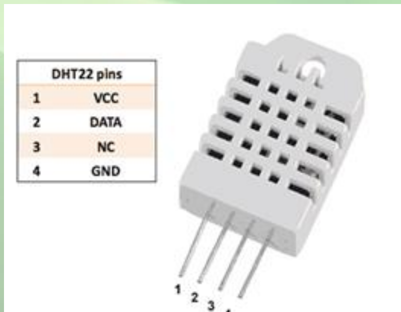

Figure 2. DHT22 Temperature and Humidity Sensor (Taştan, 2019).

Digital signals obtained from the DHT22 can be read directly by microcontrollers. For soil moisture measurements, the HL-69 hygrometer moisture sensor is also widely used. The resistance value of this sensor, which is placed into the soil and contains copper conductive paths, changes depending on the soil's moisture level. The circuit converts this resistance change into a voltage change, making it possible to obtain digital data regarding soil moisture (Taştan, 2019).

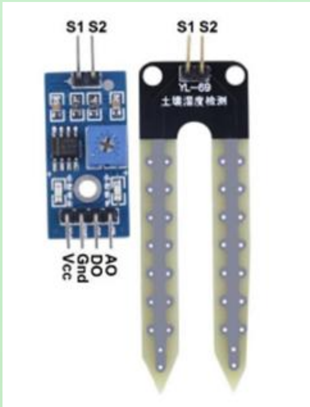

Figure 3. HL-69 Soil Hygrometer Moisture Sensor (Taştan, 2019).

Controllers

In smart irrigation systems, controllers are the components that act as the brain of the system and manage its overall operation. By analyzing data received from sensors through the communication infrastructure, they ensure the optimization of the irrigation program. Microcontrollers widely used in the market appear in many different application areas in the agricultural sector (Şahin, 2022).

A microcontroller board is used to evaluate sensor data and the most frequently preferred platform is Arduino. Thanks to its ease of programming, minimal additional hardware requirements and adaptable structure for different projects, Arduino stands out among microcontroller boards. An image of the Arduino Uno board is shown in Figure 4 (Bilgin, 2024).

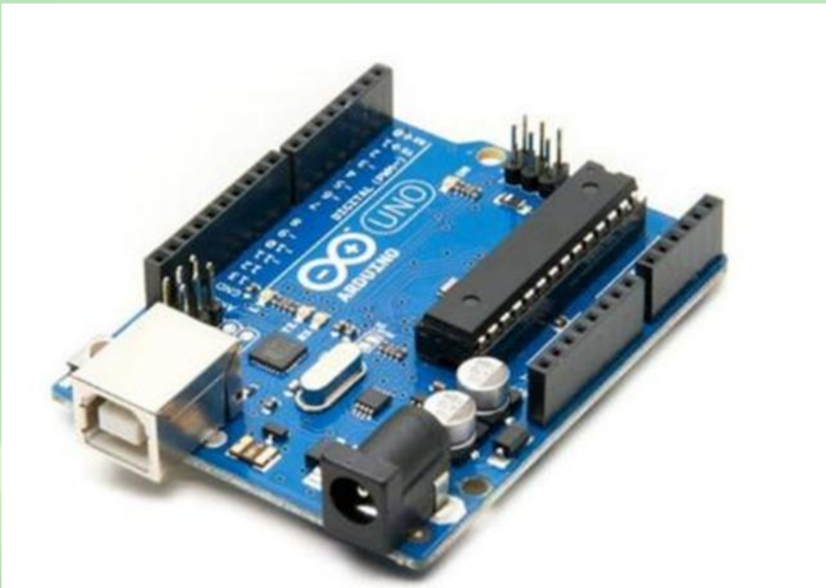

Figure 4. Arduino Uno microcontroller board (Bilgin, 2024)

Arduino can be used to create independently operating interactive systems and can also be integrated with software on a computer. Ready-made boards may be preferred, or development with original hardware design is also possible. The microprocessor (AtmegaXX) on the development board is coded in the Arduino programming language and the prepared program is uploaded to the board via the Processing-based Arduino Integrated Development Environment (IDE). The pin structure of the Arduino board is shown in Figure 5.

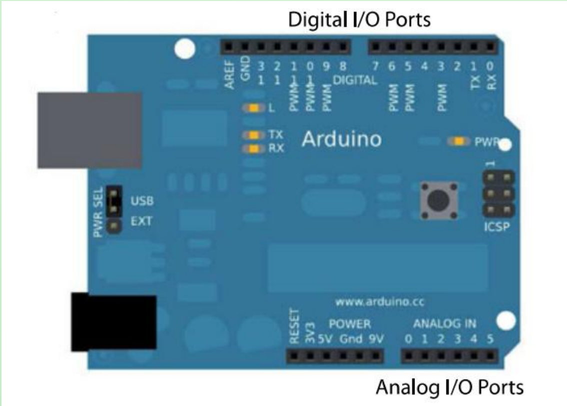

Figure 5. Arduino board pin structure (D’Ausilio, 2012).

In addition to Arduino, NodeMCU is also widely preferred as an IoT controller with Wi-Fi module support. NodeMCU contains a 32-bit RISC Tensilica LX106 microcontroller operating at 160 MHz and C++ is used as the programming language. The pin structure of NodeMCU, which can be programmed directly thanks to its mini-USB port, is shown in Figure 6, while its technical specifications are given in Table 1. Since the controller’s ADC input pin can perform 10-bit conversion for 1V, the sensor output (maximum 5V) is reduced to 1V by means of a voltage divider circuit (Taştan, 2019).

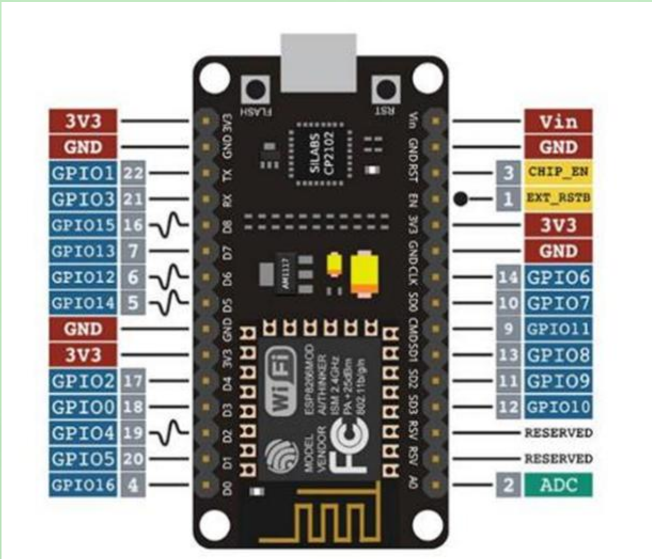

Figure 6. NodeMCU pin structure (Taştan, 2019).

Communication Systems

The communication infrastructure used in smart irrigation systems enables uninterrupted information flow by providing data exchange among sensors, controllers and other components of the system. This communication, carried out through wired or wireless networks, enables the remote management of the irrigation system and makes it easier for users to monitor the process via mobile devices, smartphones, or computers. In this way, irrigation planning suitable for field conditions can be carried out and water resources can be used more efficiently (Şahin, 2022). Technological developments have made the planning tools used in smart irrigation systems more accessible.

Especially in regions of the United States where crops requiring intensive irrigation, such as cotton, are grown, irrigation processes can be successfully managed through smartphone applications (Vellidis et al., 2016).

These mobile applications allow users to manage irrigation processes easily; thanks to notifications that optimize irrigation needs and user-friendly interfaces, critical events can be responded to quickly. Thus, sustainability in agricultural production is supported while water resources can be assessed more comprehensively (Vellidis et al., 2016).

The SIM800L module, which equips Arduino and many similar microcontroller boards with GSM communication and GPRS capabilities, is also widely used. Thanks to SIM800L, it is possible to make and receive calls, send and receive SMS messages, track location and control devices remotely. When Arduino-based system designs are combined with SMS integration, irrigation system control can be carried out as shown in Figure 7 (Alpay, 2021).

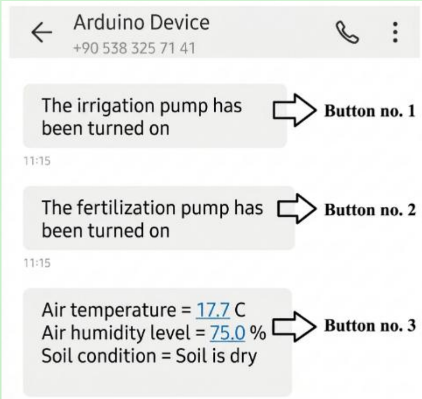

Figure 7. Warning the receiver via SMS (Alpay, 2021).

There are iOS- and Android-compatible IoT applications that enable controllers such as Arduino, Raspberry Pi, ESP32 and NodeMCU to be controlled over the internet. Among these, the Blynk application stands out by making it possible to remotely monitor and control the irrigation system.

Using the widgets on this platform, a user interface can be designed for IoT projects. Figure 8 presents the application windows of the "Smart Irrigation" user interface. In the window in Figure 8a, data received from the soil moisture sensor, time schedule settings, manual start button, lower soil moisture threshold, date-time information, Wi-Fi signal level and the moisture-time graph are shown. On the screen in Figure 8b, Twitter and e-mail notification widgets, air temperature and humidity and information on water and electricity consumption are presented (Taştan, 2019).

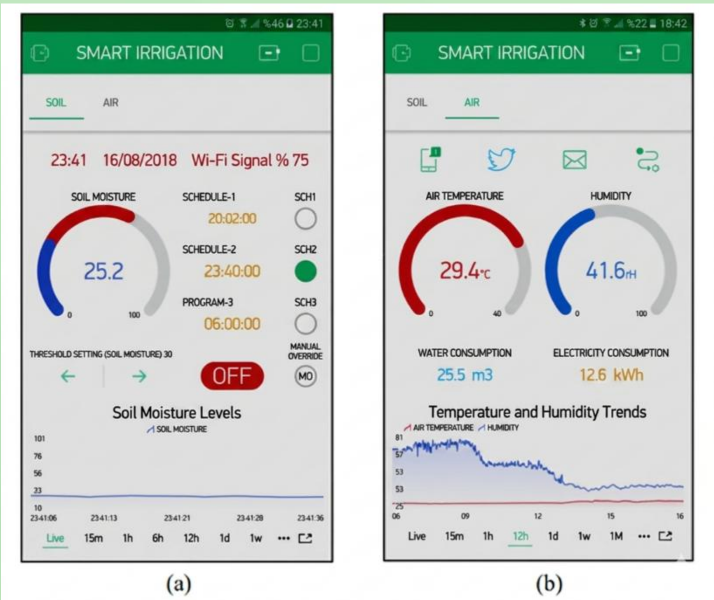

Figure 8. "Smart Irrigation" interface: a) Soil measurement b) Weather measurement (Taştan, 2019).

Valves and Sprinkler Elements

Valves and sprinkler system elements are the components directly responsible for irrigation processes in agricultural production. In a smart irrigation system, these components are equipped with flow control, pressure regulation and zone-based control features. In this way, water distribution can be carried out precisely and the amount of water required by agricultural crops can be supplied adequately (Şahin, 2022).

For example, in the United States, a soil water budget model was developed for apple trees grown under drip irrigation and seven different irrigation scheduling models based on feedforward and feedback approaches were proposed (Osroosh et al., 2016). Through these studies, the aim was to develop reliable irrigation methods that are cost-effective and not overly complex for apple cultivation in the arid regions of Washington (Osroosh et al., 2016).

A solenoid valve is used to activate the irrigation system depending on the moisture level and temperature in the soil.

Operation of the Smart Irrigation System

In the smart irrigation system, the NodeMCU controller works in an integrated manner with temperature and humidity sensors and controls the solenoid valve through the designed software, thereby activating the system. During this process, the collected data are stored in cloud infrastructure via the Blynk application. The system can be monitored and controlled through iOS and Android devices, thus enabling users to manage it remotely (Taştan, 2019). The overall structure of the system developed for smart irrigation is shown in Figure 9.

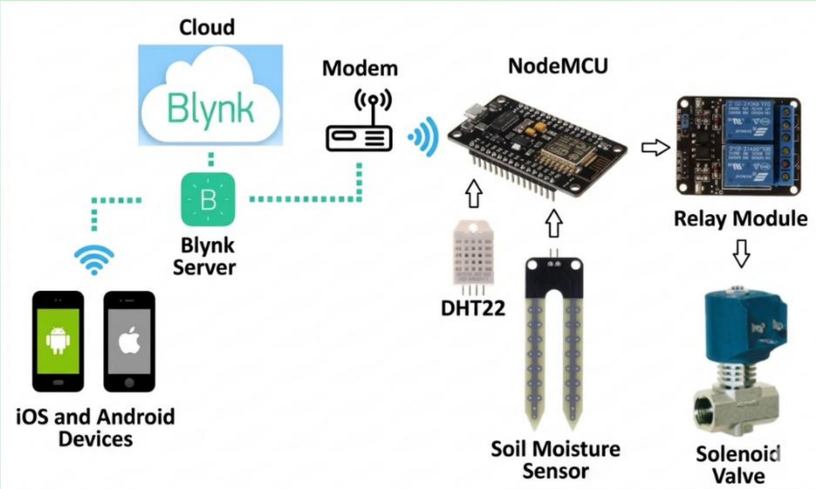

Figure 9. Structure of the Smart Irrigation System (Taştan, 2019).

Figure 10 presents the flow diagram of the "Smart Irrigation" system. In this diagram, a sample operating scenario of the system was designed. According to data received from the sensors, the "Smart Irrigation" interface obtains numerical information related to the system from the server at certain intervals. The system is managed through software and sensor control and when necessary, the user can directly intervene and direct the irrigation flow (Taştan, 2019).

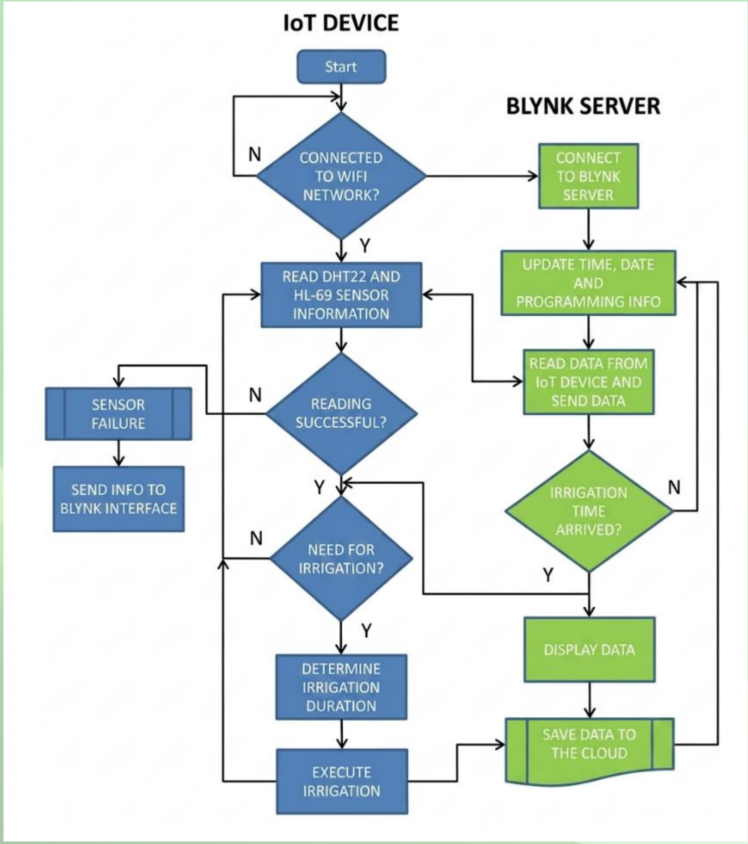

Figure 10. Flow diagram of the "Smart Irrigation" system (Taştan, 2019).

All data related to agricultural activities carried out together with the smart irrigation system are collected in cloud systems and processed through artificial intelligence technology; in this way, agricultural production processes can be improved and productivity gains can be achieved. Many parameters, from the amount of water to be delivered to the field to the amounts of fertilizer and pesticides, can be monitored within this structure.

Conclusion

The foundation of smart irrigation systems is data analysis and software infrastructure. Data obtained from sensors and other sources are processed through advanced algorithms to generate recommendations for irrigation management. In this way, users can make more informed decisions and ensure the efficient and sustainable use of water.

With the acceleration of digitalization in agriculture, irrigation automation systems have emerged as one of the most important application areas of the innovations offered by IoT technologies. In addition to the efficient use of water resources, these systems make remarkable contributions to the agricultural sector in matters such as optimizing plant health and saving labor. These automation solutions, which can be accessed and controlled remotely over the internet, provide significant economic and environmental gains for agricultural production.

Within the framework of the opportunities offered by the Internet of Things (IoT), irrigation automation systems are expected to become smarter and fully automatic in the future. This development raises productivity and efficiency standards in agriculture (Taştan, 2019). However, smart irrigation systems, like other advanced technologies, have certain limitations. While some of these limitations stem directly from the system itself, factors such as user skills, field size, land structure, crop type, access to water sources and environmental conditions can often make the process more difficult. Continuous research, development and training programs are required to improve the design and functionality of these systems. In addition, it is of great importance for policy makers and stakeholders to act in cooperation in order to expand sustainable irrigation practices (Şahin, 2022).

While the use of smart agricultural technologies is rapidly becoming widespread around the world, it is inevitable that Turkiye will also benefit from this technological transformation. However, the small-scale and fragmented structure of lands in Turkiye, the large number of enterprises, high investment costs and limited water resources make the dissemination of smart agricultural technologies more difficult. Therefore, with the participation of the Ministry of Agriculture and Forestry, the relevant institutions of the Ministry of Industry and Technology, universities, non-governmental organizations and private sector representatives, an "Agriculture 4.0 Action Plan" should be prepared to increase the use of smart agricultural technologies (Ağızan et al., 2022).

In conclusion, smart irrigation systems enable users to access remotely located agricultural areas or regions that require continuous irrigation. In this way, water and energy resources are used more efficiently and irrigation operations are carried out only when the conditions required by the soil are met. In addition, because farmers do not need to travel to the field for irrigation purposes, workload is reduced and operational efficiency increases. The system reduces the amount of fuel spent reaching the field, labor requirements, time loss and unnecessary water consumption, thereby achieving a noticeable decrease in input costs. Moreover, optimization of irrigation processes also leads to increased crop yield. Considering this reduction in input costs, it can be said that the installation costs of smart irrigation systems can be amortized in a relatively short time.

Declarations

Ethics Approval

This study does not require ethics committee approval because it does not involve any experimental applications on human or animal subjects.

Author Contributions

The authors jointly contributed to the study design, literature review, content analysis and writing of the manuscript and they together reviewed and approved the final version of the text.

Conflict of Interest

The authors declare no conflict of interest.

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