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Multifunctional multilevel moisture sensor

Sensor de humedad multifuncional multinivel

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ABSTRACT

Controlling the moisture level is especially important when irrigating various crops to obtain a resistant, stable harvest and save water resources. Over moistening of the soil adversely affects the soil structure and can lead to salinization, waterlogging, and acidification. In addition, the formation of surface water runoff from the fields causes depletion of nutrients, oxygen starvation, and, ultimately, soil degradation. The degradation of fields (areas of the field) leads to the withdrawal of the field from crop rotation (exploitation), a reduction in acreage, the need for agrotechnical measures, reclamation, and, as a result, high financial costs. Currently applied irrigation technologies lead to the withdrawal of up to 50% of irrigated land. Therefore, the technology of differentiated irrigation with constant control over the condition of the soil and plants will help eliminate these negative consequences while increasing the yield and reducing the consumption of water, electricity, and labor costs. For the implementation of this technology, sensors are needed to control the moisture and temperature of the soil at different depths and perform operational control of the water supply to the field. The implementation of a constant connection between the field and the plant with the water supply system will allow creating digital irrigation map and forming of a database about the irrigated field underlying the information and created advisory system. The system for the continuous monitoring of soil moisture and temperature at different depths is based on IT technology with data transmission via radio communication channels. It uses platforms for data transmission via such communication channels as LoRaWAN (highly economical wireless communication interface from ICBCom), GSM (Groupe Spécial Mobile - the global standard for digital mobile cellular communication), and the Internet.

Keywords: Device sensor, Analyzer, Gateway, Functional module, Humidity, Digital irrigation map, Non-volatility, Intelligent control, Radio communication, Geo-positioning

RESUMEN

El control del nivel de humedad es especialmente importante cuando se riega varios cultivos para obtener una cosecha resistente, estable y ahorrar recursos hídricos. La humectación excesiva del suelo afecta

negativamente a la estructura del suelo y puede provocar salinización, anegamiento y acidificación. Además, la formación de escorrentía de agua superficial de los campos provoca el agotamiento de los nutrientes, la falta de oxígeno y, en última instancia, la degradación del suelo. La degradación de los campos (áreas del campo) conduce a la retirada del campo de la rotación de cultivos (explotación), una reducción de la superficie cultivada, la necesidad de medidas agrotécnicas, recuperación y, como resultado, altos costos financieros. Las tecnologías de riego actualmente aplicadas conducen a la retirada de hasta el 50% de las tierras de regadío. Por lo tanto, la tecnología de riego diferenciado con control constante sobre la condición del suelo y las plantas ayudará a eliminar estas consecuencias negativas al tiempo que aumenta el rendimiento y reduce el consumo de agua y electricidad, y los costos de mano de obra. Para la implementación de esta tecnología se necesitan sensores que permitan controlar la humedad y temperatura del suelo a diferentes profundidades y realizar el control operativo del abastecimiento de agua al campo. La implementación de una conexión constante entre el campo y la planta con el sistema de suministro de agua permitirá crear un mapa de riego digital y formar una base de datos sobre el campo regado que sustenta el sistema de información y asesoramiento que se está creando. El sistema de monitorización continua de la humedad y temperatura del suelo a diferentes profundidades está basado en tecnología informática con transmisión de datos a través de canales de comunicación por radio. Se utilizan plataformas para la transmisión de datos a través de canales de comunicación LoRaWAN (interfaz de comunicación inalámbrica altamente económica de ICBCom), GSM (Groupe Spécial Mobile, el estándar mundial para la comunicación celular móvil digital) e Internet.

Palabras clave: sensor del dispositivo, analizador, gateway, módulo funcional, humedad, mapa de riego digital, no volatilidad, control inteligente, comunicación por radio, geoposicionamiento.

1. INTRODUCTION

The main trend in the development of the agricultural market is the demand for high-precision farming, the introduction of new digital technologies, and robotics in the irrigation of crops. The market situation is determined by an increase in demand for energy and resource-saving technologies.

Controlling the moisture level is very important in the irrigation of various crops to obtain a stable harvest and save water resources. Over moistening of the soil adversely affects the structure of the soil and can lead to salinization, waterlogging, and acidification. In addition, the formation of surface water runoff from the fields causes depletion of nutrients, oxygen starvation, and, ultimately, soil degradation. The degradation of fields (areas of the field) leads to the withdrawal of the field from crop rotation (operation), a reduction in acreage, the need for agrotechnical measures, reclamation, and, as a result, high financial costs.

The research aims to solve the technical problem of creating an IT system that provides the formation of a digital irrigation map, considering the type of irrigated crop and the type of irrigation system, and establish feedback between the agricultural crop, soil, and a digital irrigation map. This creates an intelligent irrigation system that provides a differentiated supply of water and fertilizer. As experience shows, water saving depending on zoning, crops, and feeding method is up to 200% with sprinkler irrigation and up to 20% with drip irrigation.
A multifunctional sensor device measures the moisture and temperature of soil and air in real-time, performs constant monitoring, forms databases and knowledge of the controlled field, and controls the water supply system for irrigating crops by conducting differentiated irrigation. The sensor is a combined device that implements the technology of differentiated water supply to the field and determines its location using the GLONASS and GPS systems (Albergel, Rüdiger, Pellarin & Calvet, 2008; Fartukov & Zemlyannikova, 2018; Yu. Mulev, Arefiev, Belyaeva & M. Mulev, 2011).

2. MATERIALS AND METHODS

The multifunctional sensor receives data using the combined inductive-capacitive principle for soil moisture measurement, which allows a unified calibration of temperature and moisture measurement of soil in a wide range of types and depths.

The soil moisture determined by the device considering the physical properties makes it possible to use the measured electrical parameters with subsequent mathematical processing of the measurement results in agrometeorology, agriculture, construction, and forestry.

A highly economical wireless communication interface (LoRaWan) allows for the two-way radio data exchange between a humidity sensor, a radio transceiver, and an executive module, which forms a single network (Fig. 1).

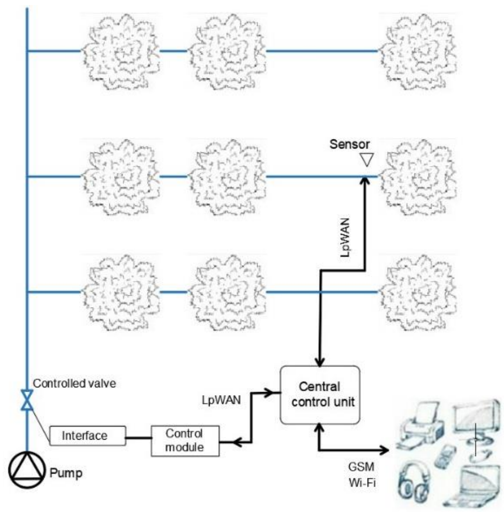

Figure 1: Approximate scheme of irrigation and control of the main irrigation line for monoculture

3. RESULTS

A multifunctional multilevel moisture sensor solves the problem of the remote measurement of soil moisture and temperature at three depths simultaneously, as well as monitoring and controlling the water supply with consideration of the required soil moisture level at a controlled depth. The technical result is an increase in the efficiency and accuracy of measuring soil moisture and temperature at different depths simultaneously in real-time and the formation of a database and differentiated watering of crops and other plants.

The principle of controlling the inductive-capacitive change in the frequency characteristics of the oscillatory circuit as a function of the change in ambient humidity was adopted for soil moisture measurement. The calculation, processing, storage, and transmission of the received data and control of operating modes according to the user's settings are performed by the built-in microprocessor module.

The use of distributed inductance makes it possible to automatically consider the physical properties of the soil, such as diamagnetic or paramagnetic, which affect the filtering capacity of the soil. This allows working with calibrated moisture values for different soils.

The sensor is self-powered by a built-in battery with highly efficient recharging from a built-in solar battery.

The choice of the operating mode ensures a positive energy balance of the sensor power supply in the presence of sunlight for 3–4 hours a week.

LoRaWan allows for two-way radio data exchange with the receiving unit (Fig. 1), thereby transmitting measured data and obtaining the energy characteristics of the sensor. The interface uses a dedicated frequency range of 850–940 MHz, which is allowed in almost all countries.

Fig. 2 shows a diagram of the inclusion of a moisture sensor in the control system for a differentiated water supply to the field for irrigating crops.

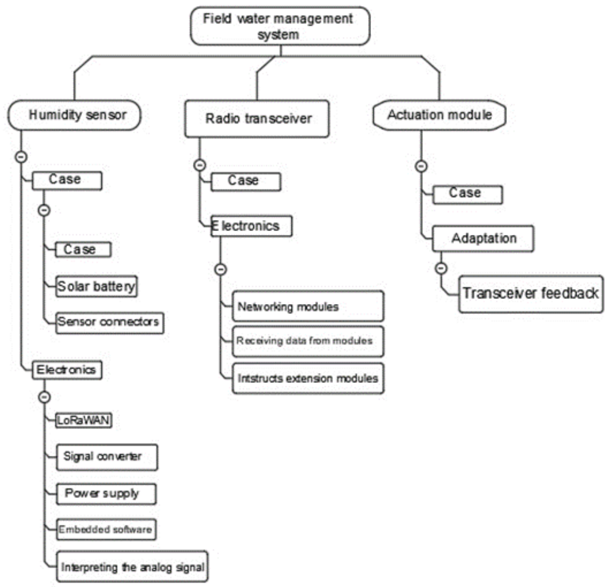

Figure 2: Scheme for connecting a moisture sensor to the control system for a differentiated water supply to the field for irrigating crops.

4. DISCUSSION

The sensor has a built-in microprocessor control unit and a built-in power supply unit consisting of a compact lithium polymer (or similar) battery. The built-in power controller monitors the voltage and state of charge of the battery from the solar panel mounted on the sensor.

The radio interface for communication with the central control module uses the modern Internet protocol, LoRaWan, which allows it to work autonomously for more than three weeks without recharging from solar energy.

Moisture sensors, located at three depths, have a non-contact method for measuring soil moisture at working levels of 10 cm, 40 cm, and 60 cm, which, if necessary, can be changed to other values during the sensor manufacturing process. The sensor readings are transmitted to the central unit via the Internet channel with consideration of the automatic correction of soil properties (water absorption, filtration, etc.). The measured and transmitted data have little dependence on the different sections of fields with different soils. The sensor body consists of a cylindrical measuring and control part. The measuring section has a diameter of 2–4 cm and a length of 50–100 cm. Temperature sensors are located at the bottom of the measuring section and monitor the soil temperature at the required depth. The upper sensor is located in the upper part of the sensor and measures the local air temperature.

Soil moisture measurement is performed by sensors of the detector (Bartalis, Wagner, Naeim & Hasenauer, 2007; Carreiras, Quegan & Le Toan, 2017; Fartukov & Zemlyannikova, 2018; Koryakov & Zaporozhets, 2002; Piepmeier, Kim, Mohammed & Eastwood, 2013; Prashant, Srivastava & Kerr, 2016). The principle of soil moisture measurement is based on the control of the inductive-capacitive change in the frequency characteristics of the oscillatory circuit as a function of the change in the humidity of the surrounding space, W = F (f), where W is the soil moisture and f is the frequency of the oscillatory circuit. The sensors are located at three levels along the length of the measuring part of the sensor. The sensor consists of an inductance coil; to the left and right of them, there are solid cylindrical electrodes 5–10 mm wide, which are functional capacitor plates and, together with the distributed inductance, form an oscillatory circuit.

Due to a special program recorded in its memory, the microprocessor sends a temporary signal to the sensors and measures the change in the frequency of the oscillatory circuit, which (frequency) depends on the presence of moisture (water) in the area of the sensor. According to the calibrated curve W = k * F (f), where k is the calibration factor in the microprocessor memory, the sensor calculates the percentage of soil moisture and transmits this value to an external receiving unit. The calibration coefficient k is determined in advance by comparing the data obtained by the sensor with a one-time sampling of the measured soil and subsequent determination of moisture by the volume-weight method, which amounted to 2%–3%.

The distributed inductance located at the center of the sensor reacts to the para- or diamagnetic component of the soil. The influence of the humidity of the soil surrounding the sensor changes the frequency properties of the oscillatory circuit.

The principle of consideration of the magnetic property of the soil makes it possible to automatically correct moisture parameters for different soil compositions, which allows measuring with a sensor in a wide range of soils to grow agricultural and other crops. A functional block diagram of the sensor is shown in Fig. 3.

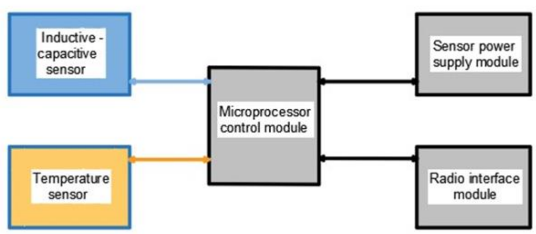

Figure 3: Functional block diagram of the sensor

A schematic representation of the sensor design is shown in Fig. 4a, and the installation diagram of the inductive-capacitive sensor is shown in Fig. 4b.

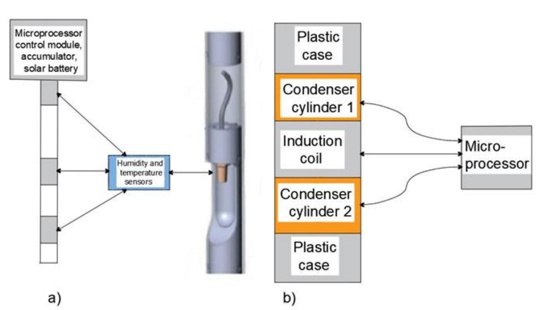

Figure 4: Sensor design (a) and diagram of connecting sensors to the microprocessor (b)

The sensor can be supplemented with a liquid crystal indicator, which displays soil moisture data at three levels, the temperature at depth and soil surface, battery charge level, geolocation, and solar battery. A scheme of the 3D model of the sensor developed is shown in Fig. 5.

Figure 5: Scheme of the 3D model of the sensor (a) and the upper part of the sensor (b)

At the bottom of the sensor inside a pointed cone, there is a sensor for measuring the soil temperature.
An external antenna is used for reliable radio communication. Fig. 5b shows the embodiment of a sensor with a liquid crystal display for data presentation and antenna communication.

The sensor is part of the LoRaWan network, which includes the following elements: end device, gateways, network server, and application server.

The end device is designed to perform control or measurement functions. It contains a set of necessary sensors and control elements.

A gateway is a device that receives data from end devices using a radio channel and transmits it to the transit network. The transit network can be Ethernet, Wi-Fi, or mobile radiotelephone networks. The gateway and end devices form a star network topology. This device contains multichannel transceivers for simultaneously processing signals in several channels or several signals in one channel. Accordingly, several such devices provide radio coverage of the network and transparent bidirectional data transmission between the end devices and the server.

The network server is designed to manage the network by setting the schedule, adapting the speed, storing, and processing the received data.

The application server remotely controls the operation of the end devices and collects the necessary data.
The radio transceiver receives data from the humidity sensor and transmits it to the computer. The radio transceiver provides the transmission of a request to the sensor via a radio frequency channel, reception of information from the sensor via the same channel, as well as its primary processing and transmission to a computer via the USB interface. The receiving unit is a device consisting of a plastic case and an electronic board (Fig. 6a).

In the plastic case of the radio transceiver, there are LEDs displaying the operation of the transceiver.

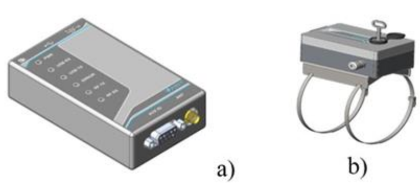

Figure 6: Radio transceiver (a) and an executive module with attachment to the water supply pipe of the irrigation system (b)

The executive module is designed for the remote control of motorized irrigation cranes for agricultural crops installed on the pipes of the irrigation system.

The executive module issues the command to open or close the watering valve at the command of the central device. The signal arrives over a single network with a specified protocol for the addressed messages.

The executive module is a device consisting of a sealed case (IP-65) with a lock and a loop, which contains two boards: the main board and a board with connectors and a battery (Fig. 6b).

Fig. 7 shows the irrigation scheme by combining the plots. It provides irrigation for different types of crops planted in the same field. The minimum and maximum numbers of sections are determined by the LoRaWAN range.

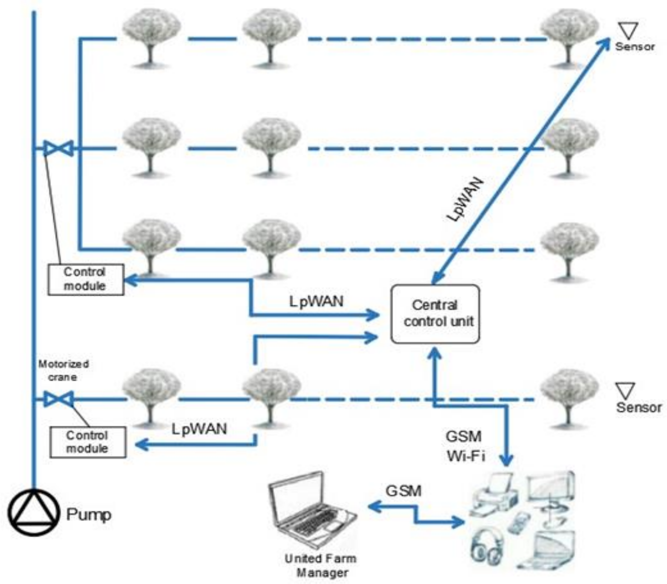

Figure 7: Irrigation scheme by combining the plots

Fig. 8 shows multifunctional sensors installed in the field and controlling the water supply through a 50-mm main pipe.

Figure 8: Multifunctional sensors installed in the field

5. CONCLUSION

The developed multifunctional sensor has a nonvolatile power supply and operates in automatic mode. The applied principle of inductive-capacitive measurement makes it possible to determine the temperature and humidity in various types of soils.

The applied accounting for the magnetic properties of the soil made it possible to automatically adjust the calibration curves of the sensor for different soil compositions, thereby measuring different types of soils. The temperature and humidity of the air and soil are simultaneously monitored in real-time at three depths. The multifunctional humidity sensor works as a measuring device and as an integral part of intelligent irrigation systems, which consists of a radio transceiver and an executive module.

It forms a database, a digital irrigation map, and an information and advisory system. This database also records all information about the volume of water supplied at each site and field, the time of its supply, and energy consumed. An analysis of the irrigation system is performed, and statistical reporting and variability are formed after the end of the irrigation season and the determination of the yield. Based on the analysis, an irrigation plan for the next season is proposed, which can be applied without changes, amended, or not applied. Transmitting data of the measured values by the sensor is performed via the radio channel of the LoRaWan platform at a distance of up to 3.0 km, which makes it possible to control the water supply of the irrigation network to the field.

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