Robotic Irrigative Complex with Intellectual Control System "CASCADE"

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Abstract: The design, production and introduction of agricultural irrigation equipment of a new generation and the widespread use of automation functions of control systems in the agricultural sector are the basis for establishing irrigated agriculture. Raising the technical level of sprinkler machines requires expanding the functions of automation and control systems, improving irrigation technology, which ensures the rational use of water, electric energy and human labor. Existing technologies for irrigation with wide-angle circular sprinklers have the disadvantage. The irrigation with a constant rate in most cases does not correspond to the required moisture content in different parts of the irrigated field, which leads to excessive consumption of irrigated water, increased runoff and soil erosion. The developed module of the intelligent system let us change the irrigation rate in accordance with the level of moisture reserves of irrigation areas in real time, based on the readings of sensors of the weather station without human intervention. The proposed technology was implemented during the operation of the robotic irrigation system "CASCADE" installed in the Volga State Scientific Production Association. A comparison of the performance of an electrified irrigation machine and a robotic irrigative complex using the proposed irrigation technology showed significantly improved environmental and economic indicators of irrigation. In particular, the saving of irrigation water was about 7.0%. The introduction of digital technologies can significantly improve the quality of irrigation and crop yields while saving resources, as well as reduce the environmental burden on the soil significantly.

Keywords: sprinkler, robotic irrigative complex, resource saving, energy saving, intelligent control system.

1. Introduction

Agricultural production of the Saratov region is carried out in difficult climatic conditions. The most characteristic feature of the climate in the Volga region is the dramatically changing moisture content, as well as the problem of increasing land water availability. The struggle to increase soil fertility is waged unsystematically in various ways. This significantly reduces the effectiveness of the technologies used. There are requirements to improve the quality of irrigation, which consists in the ratio of climate data and the level of functioning of irrigation systems.

Improving the quality of irrigation can be achieved by changing the irrigation rate in accordance with the level of moisture reserves in the field in real time, adapting the irrigation regime to conditions changing during the irrigation period. This requires

improving the control system of machines, expanding their technological capabilities and introducing information technologies.

Foreign manufacturers widely use elements of "precision farming". Sprinkler machines have modifications with intelligent control system but they are not available on the Russian market due to various reasons. Such systems are not adapted for Russian agricultural producers: a complex management interface, the difficulty of setting up and configuring the functionality, the problem of troubleshooting in emergency situations, etc. [1–9].

There are no digital technologies and technical means of irrigation of Russian production. There is only a partial implementation of individual system elements which are purchased abroad and adapted for the Russian market. Therefore, the feasibility of creating own base and carrying out theoretical and experimental research in this area is obvious.

2. Materials and Methods

A number of analytical actions from the theory of automation at the first stage of creating an intelligent control system are performed [10]. In order to automate irrigation it is necessary to select all the parameters that characterize the process and divide them into managed and unmanaged. The parameters of the irrigation system, for example, a circular sprinkler such as speed of movement, repeatability, diameter of the water distribution pipe and others will be taken as managed. Unmanaged factors will be considered as initial data for the implementation of a specific decision. These are the conditions of the natural-climatic zone in real time.

Let us consider the irrigation technology of a robotic irrigative complex.

The average speed of the last running carriage depending on the cycle time and slipping coefficient can be determined by the expression [11, 12], m/s:

$$V_{av} = 60 \Delta S m \beta_s / t_c, \quad (1)$$

where $\Delta S m$ – step of movement of the irrigation complex, m; t – time of movement, s;

β_s - slip coefficient. The time of each cycle for the irrigation complex "CASCADE";

$t_c = 100$ s.

The initial moisture reserves before irrigation are determined by the formula, m^3 / ha [11, 12]:

$$W_0 = 100 h \gamma \beta_h, \quad (2)$$

where h is the estimated depth of soil moisture, mm;

β_h - soil moisture equal to the lowest moisture capacity, % of the dry soil mass;

γ - soil density in kg / m^3 .

The water balance equation can be represented in the form [12]:

$$Et = (W_0 - W_k) + M + P + V_{gr} - L_0 \quad (3)$$

where Et - total water consumption, mm; W_k - moisture reserves after irrigation, mm;

M - irrigation rate, m^3 / ha ;

P - precipitation;

V_{gr} - groundwater recharge;

L_0 - loss on drain and filtering. To simplify the P

Note: V_{gr} and L_0 can be neglected.

We also neglect fluctuations in water consumption (E , mm / day) during irrigation (t , days), and also assume the absence of rainfall during irrigation.

Moisture reserve before the passage of the irrigation complex [11, 12], m^3 / ha :

$$W_k = W_0 - Et, \quad (4)$$

where t is the time from the initial to the final point of irrigation.

This is the turnaround time of the irrigation complex at watering in one circle. This is the transit time of a certain part of the circular arc at watering half a circle with reverse.

Irrigation rate is determined by the formula, m^3/ha [11, 12]

$$M = 100hy_{gr} (\beta h - \beta_{0.8}h), \quad (5)$$

where βh - humidity corresponding to the lowest soil moisture capacity;

$\beta_{0.8}h$ is the moisture content corresponding to the pre-irrigation threshold of 80% soil humidity.

Consider the operation of the irrigation complex if it returns to the point φ , moving in the opposite direction, that is, reversely.

The condition for issuing a given irrigation rate for several passes of the irrigation complex, m^3 / ha [11, 13, 14]:

$$M = M_1(\varphi) + M_2(\varphi) + M_3(\varphi) \dots + M_n(\varphi), \quad (6)$$

where $M_1(\varphi)$ - irrigation rate when the irrigation complex moves from the point $\varphi = 0$ (first pass), m^3 / ha ;

$M_2(\varphi)$ and $M_3(\varphi)$ - irrigation rate for the second and third passes, m^3/ha ;

$M_n(\varphi)$ is the irrigation norm for the n^{th} passage.

When moving in the forward direction, days [2–5]:

$$t = \frac{1}{1440 K_{CVT}} \int_0^{\varphi} \frac{d\varphi}{V_{CP}(\varphi)}, \quad (7)$$

where K – time factor;

$V(\varphi)$ - speed of movement of the irrigation complex, m/ min.

Precipitation layer for the passage around the irrigation complex:

$$h = \frac{120 Q_M}{R_M V_{CP}}, \quad (8)$$

where Q is the consumption of the irrigation complex, l/s;

R - irrigation radius equal to the length of the water supply pipeline of the irrigation complex, m.

The irrigation complex should ensure the issuance of the irrigation rate M , m^3 / ha :

$$M = \frac{1200 Q_M}{R_M V_{CP}}, \quad (9)$$

Then, when passing the incomplete circle [11, 15, 16]:

$$M'_1 = 2\pi \frac{1200 Q_M}{\ell_{CEK} V_{CP}},$$

where ℓ - arc length of the irrigation sector, m.

$$t = \xi \int_0^{\varphi} M_1(\varphi) d\varphi, \quad (10)$$

$$\xi = \frac{s}{432 \cdot 10^3 K_{CVT} Q_M}. \quad (11)$$

where s is the path passing by the last running trolley, m.

The maximum value of the path traveled by the running trolley in one direction corresponds to the length of the circular arc:

$$s_{MAX} = \ell = 2\pi R, \quad (12)$$

The change in moisture reserves in the soil in front of the irrigation complex in the forward course when watering part of the circle can be represented as:

$$f_1(\varphi) = W_0 - 10E\xi \int_0^\varphi M'_1(\varphi) d\varphi, \quad (13)$$

After the passage of the irrigation complex at time t , the moisture reserves will be determined:

$$W_1 = f_1(\varphi) + M'_1(\varphi), \quad (14)$$

If the moisture reserves in the soil are represented by the function $f_2(\varphi)$ when moving in the opposite direction before the irrigation complex, then behind it they are determined from the expression:

$$W_2 = f_2(\varphi) + M'_2(\varphi), \quad (15)$$

The irrigation complex enters the point φ again after a time interval Δt [11]:

$$\Delta t = \xi \int_\varphi^s [M'_1(\varphi) + M'_2(\varphi)] d\varphi = \xi(s - \varphi)M, \quad (16)$$

$$M'_1(\varphi) = 2\pi \frac{1200Q_M}{\ell_{CEK} V_{CP}(\varphi)} [1 - e^{10E\xi(\varphi-s)}], \quad (17)$$

$$M'_2(\varphi) = 2\pi \frac{1200Q_M}{\ell_{CEK} V_{CP}(\varphi)} e^{10E\xi(\varphi-s)}. \quad (18)$$

Setting the path that the last running trolley passes, you can determine the optimal value of the irrigation rate in one and in the opposite direction. Dividing the irrigation circle into sectors, with a change in speed in each sector, we can express [15, 16]:

$$M'_i = 2\pi \frac{1200Q_M}{\ell_{CEK} V_{CP}(\varphi)} \left[1 - \frac{1}{(1 + 10E\xi \ell_{CEK})^{n+1-i}} \right], \quad (19)$$

where i is the number of the plot from the beginning of the field, $i = 1, 2 \dots n$;

n is the total number of sections of the partition;

M'_i - irrigation rate in the i^{th} plot.

Note: Here $l_{\text{sec}} = 2\pi R_m / n$.

Precipitation, groundwater recharge and losses in runoff and filtration can be taken into account using the correction factor ψ . Expressions (18) and (19) characterize a sufficient rate of irrigation in the irrigated area.

At the second stage of creating an intelligent control system, a decision-making program for watering and its parameters is modeled from expression (19). The main task when planning irrigation and setting the operating mode of the machine is to assess the influence of the main factors that determine the characteristics of irrigation, as well as factors that make it necessary to adjust the irrigation regime. It is necessary to analyze information and make a decision on making changes to the planned irrigation regime based on the results of sensor readings and operational weather data.

Required information for control are the following: soil moisture at the beginning of the growing season (every five days, ten days), control measurements of the irrigation norms obtained and the uniformity of their distribution over the area and depth in each sector or irrigation area, collection of information about the state of crops and the progress of agricultural activities. On the basis of the data obtained, a decision is made on the appropriateness and extent of adjustments for irrigation of agricultural crops.

The operating mode of sprinkling equipment should be adapted to the soil and climatic conditions of the region, as well as the moisture content in the soil and atmosphere in real time. A block diagram of a simplified view of the program is shown in Figure 1.

Figure 1. Block diagram of the program of the intellectual system of the irrigation complex

3. Results

The created program and theory of operation of the sprinkler machine was verified experimentally. A logical controller of the OWENLogic type was taken as a logical element of theoretical calculations. Its executive circuit of power equipment was developed on the domestic element base, Figure 2.

Figure 2. Appearance of the board of the executive unit and controller in the device for synchronizing movement in a line

The robotic irrigation complex "CASCADE" with an intelligent control system designed and implemented at Saratov State Agrarian University named after N.I. Vavilov is intended for irrigation of feed, grain, industrial crops, including tall stalk crops, Figure 3 [11, 15, 16].

The developed module of the intelligent control system ensures the monitoring of the functional state and operation of the machine and pump station with the transmission of information to the operator console, the subsequent processing and analysis of the received data (OWENLogic software in CoDeSys language).

Figure 3. Robotic irrigation complex "CASCADE"

The completed module on the basis of a domestic-made programmable logic controller make it possible to water in time with application the necessary fertilizers and pesticides according to a given algorithm, to control water consumption and fuel level control in the generator set and other parameters. The control system is able to monitor the condition of the soil, change the irrigation rate according to a given algorithm and depending on weather data in real time without the direct involvement of a person. By adding analysis, conversion, output and data transfer to the functionality of the logical controller's system and program, it is possible to expand the control parameters and their operational control from a mobile device via GLONASS satellite communications.

The developed intelligent irrigation control system includes:

- management system;
- control module of pumping station;
- operator panel with a software and hardware complex;
- weather station for monitoring and forecasting weather conditions;
- wireless autonomous sensors for monitoring irrigation parameters.

Comparative experimental studies were carried out on electrified sprinklers of circular action "Kuban-LK1M" (CASCADE) and the irrigation complex "CASCADE" with the developed control system according to the proposed technology in neighboring irrigation areas [16]. The irrigation season was divided into decades during which precipitation, humidity and the irrigation rate obtained were noted.

The irrigation norm for standard technology was introduced for 4 irrigation of 400 m³ / ha in 2018 and 450 m³ / ha in 2019. The irrigation norm for optimized technology in 2018 was 1.510 m³ / ha, in 2019 – 1.680 m³ / ha, which 90 and 120 m³ / ha less respectively.

The data obtained are presented in Table 1.

Table 1. Comparative data on standard and optimized irrigation technology

Indicator	Year	
	2018	2019
Machine length, m	497	497
Irrigation area, ha	77.5	77.5
Irrigation rate, m ³ / ha:		
standard technology	1600	1800
optimized technology	1510	1680
Water saving, m ³ / ha	90	120
Water saving,% of total volume	5.6	7.1
Total water savings for 1 machine, m ³	2325	8525

4. Discussions

It is relevant to conduct research and development studies aimed at creating technologies based on digital, intellectually-advising systems for managing agricultural machines that provide fertilizer application and watering.

It is necessary:

- to develop new principles, methodological approaches, methods, algorithms for the transition to intelligent, digital agriculture, based on the use of automated decision-making systems, automation and robotization of irrigation systems;
- to develop system control parameters that provide remote control of work, collection, processing and analysis of data on the progress of irrigation processes;
- to implement digital technologies and obtain experimental data with the aim of improving the quality of irrigation and crop yields while saving resources (fuel, water, energy, labor, etc.), as well as reduce the environmental burden of climatic zones of watering by introducing intelligent digital technology;
- to sale competitive scientific and technical products in the market and import substitution is necessary.

5. Conclusions

The developed technology was implemented on the Kuban-LK1M sprinkler machines and the CASCADE irrigation complex used on irrigated fields in LLC "Our Business" (the village Krasny Yar, Engelsky District of the Saratov Region) and in the Scientific Production Association "Volga" (the village Stepnoye, Engelsky District of the Saratov region) [12, 17]. Comparison of standard and proposed technologies showed that irrigation using the proposed technology on CASCADE irrigation complex makes it possible not only to save irrigation water up to 7% but reduce the environmental burden on nature and facilitate human labor greatly.

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