The 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications
18-21 September, 2019, Metz, France

Application of Wireless Sensor Networks for Digital Agriculture

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***Abstract*—Modern precision and digital agriculture for efficiency increasing requires development and implementation of new information and communication technologies, including wireless ones. The authors developed wireless sensor network (WSN) for express-diagnostics of agricultural plants' state, created the appropriate hardware, software and methodological support. The developed network now is implemented and under field tests both in open agricultural lands and in smart greenhouses. The main contribution of this paper is the design and fast-prototyping of WSN, taking into account the requirements of application task concerning field usage, long time of autonomous operation and measuring environmental parameters. That caused modeling of developed network to estimate its parameters before practical realization.**

***Keywords*—wireless sensor network; digital agriculture**

I. INTRODUCTION

Progress of Internet, information and communication technologies, reliable links of communication, cloud technologies and digital platforms guaranteed appearance of open information system and global industrial networks, which step outside individual enterprise and cooperate among themselves. Such systems and networks have influence on all sectors of modern economics and business and move industrial automation on new phase – Industry 4.0. Industry 4.0 is updated concept of "smart manufacturing" and new step of digitization of manufacturing and industry. Such technologies and concepts as Internet of things (IoT), big data, predictive analytics, cloud and fog computing, machine learning, machine interaction, artificial intellect, robotics technology, and 3D-printing play the leading part on current phase of digitization.

In the classic sense the "digital economics" is activity where key manufacture facilities are digital data and their using, which considerably allow to increase effectiveness and productivity in different types of economic activity. Digital economics is based on active implementation of innovation, information and communication technologies in all types of economic and spheres of society life activity, and allows to increase effectiveness and competitiveness of individual companies, economics and standard of life. Digital technologies replace traditional business models, production chains and processes, causes appearance of new products and services, platforms and innovations.

Recent advancements and achievements in WSNs have provided an opportunity for numerous applications in agriculture, environment protection, healthcare etc. It has become a promising area of scientific and engineering researches due to its large potential. These researches focus on the applications of WSN.

Firstly authors developed WSN [1] for express-diagnostics of plants' state on large territories. WSN measure only the general state of plants using chlorophyll fluorescence induction (CFI) method. But the growth of agricultural plants is impacted by several environmental parameters, such as the temperature and humidity of air and soil, and some others. In natural conditions these variable parameters exercise its influence on plants in wide range, but the measured parameters of plants' state are more precise when these environmental parameters are in limited or optimal range, required by plants.

So, environmental parameters' influence on plants' state has to be considered during decision making on agrarian plant care and protection. To avoid such influence on managerial decision it is necessary to modernized proposed WSN [1] by adding additional sensors, developing proper software and methodical support to take into consideration a large variability of environmental parameters

Thus the main contribution of this paper is the design and fast-prototyping of WSN, taking into account the requirements of application task concerning field usage and long time of autonomous operation. That caused modeling of developed network to estimate its parameters before practical realization.

II. STATE OF THE ART

Foregoing caused agrarians' interest to implementation of information technologies in agriculture. New tendency in agrarian sphere, revolution in modern agriculture with slogan "agriculture without farmer", and with implementation of latest achievements in information technologies which remove influence of "human" and climatic factors on agrarian technologic processes. Digital agriculture is completely based on using of digital technologies.

There are seven important factors of digital agriculture: an integrating digital platform; a sequence of actions; automation of analytics; soil as the productive asset; digital description of the seed or crop; weather prediction; controlling of the stress influence on the plants.

Now many projects, concerning the application of WSN in the various areas of human activity, have already been completed and implemented or are under the researches and development. Detailed analysis of the market of wireless technologies allowed choosing several examples of successful projects in the area of precision agriculture with use of wireless data transmission units.

The company "MyOmega System Technologies" [2] developed sensory platform "TracoVino" for monitoring the state of vineyards in remote mode. Wireless sensors, which are placed directly on vineyards, acquire data about temperature and humidity of air, light intensity and soil humidity. Additional sensors collect and transmit data about leaf humidity, acidity level and soil feeding power. Swiss commercial system "Predicting Diseases of Vine (PreDiVine)" [3] is intended to fight against pests of vine. Wireless sensors are allocated on buds and stems of the vine for measuring air temperature. Sensors transmit the data via wireless channel to computer device, which models the evolution of pest on the base of temperature data. Hungarian company "AgroSense" [4] developed wireless sensor network for agricultural sector. Network collects data of soil temperature, and humidity, leaf wetness and thus controls the watering. It should be noted that there are many similar projects with almost similar functionality and use hardware-software tools.

We want to point, that in all mentioned projects, technologies and examined papers proposed systems for measuring different parameters of soil, plants and environment including temperature, humidity, biochemical parameters of plants, even sound range etc. But any system does not measure parameters of photosynthesis – the main process of plant vital activity. If it is necessary to estimate plants state and influence of stress factors of natural or anthropogenic origin on them, the most effective and informative way for accurate estimating of plant state is to measure the photosynthesis parameters in plants [1].

Application of newest wireless tools and WSN [19] as part of IoT technology in precision and digital agriculture is the actual problem today. So, WSN and IoT are very promising technologies for farming including digital agriculture [12, 13, 14, 15, 16, 17].

III. WSN Application

WSN – multilevel, distributed networks, built on base of self-organization principles, with large quantity of sensors and actuating mechanisms, which integrated by radio channels. Realization of sensor networks depends on specific requirements of application. Networks could deploy as on open areas, so in enclosed space, for example in laboratories, greenhouses and conservatories. WSN, designed for precision or digital agriculture, needs to fit with requirements which are conditioned by the field of usage. These requirements are failure-resistant, scalability, charges on production, type of operational environment, sensor network topology, hardware constraints, data communication model and power consumption. Taking into consideration all above mentioned requirements, authors developed WSN within international project (Fig. 1).

All network nodes were built on the wireless microcontroller JN5168 [7], manufactured by NXP company. Every node includes 32-bit RISC-processor with a clock speed equals 32 MHz and wireless unit, compatible with IEEE802.15.4 standard. ZigBee Pro stack is used as wireless protocol for network organization and data transferring.

WSN measure the general state of plants using CFI method [5] without plant destruction. Using the curve of chlorophyll fluorescence induction allows diagnosing influence of one or other influential factor on the plant's state [8, 9].

Wireless sensor network consists of network coordinating node (1), certain number of wireless sensors (2), ZigBee/USB converter (3), and network concentrator (acts as remote PC) if necessary.

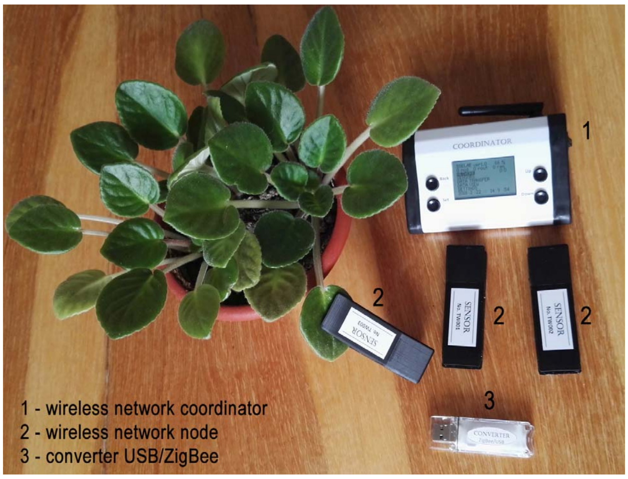

Figure 1. Sample of developed wireless sensor network

Developed WSN is well integrated in digital farming conception. With its help we can simultaneously get information about state of large quantity of plants on large areas. Also we have possibility to integrate and use simultaneously wireless sensors for measuring air temperature, soil humidity and other environmental parameters. Sensor network allows defining soil contamination by pesticides, heavy metals, estimating vital activity of plant after water deficit, low temperatures, bringing of pesticides. We can analyze and structure information, which was obtained from the sensors with help of specially developed by authors the analysis software tools "CFIAnalyzer" and "FAnalyzer" (more detailed in VI). These software tools are intended for analysis of large quantity of chlorophyll fluorescent induction (CFI) curves. Developed software combines CFI curves obtained from a large amount of sensors of wireless network, calculates average and essential parameters of CFI curves, determines characteristic points of CFI and stores them to Microsoft Excel compatible files or other formats for further processing and analyzing.

Special applied software was created to control operation of WSN. Main window of software is shown on Fig. 2.

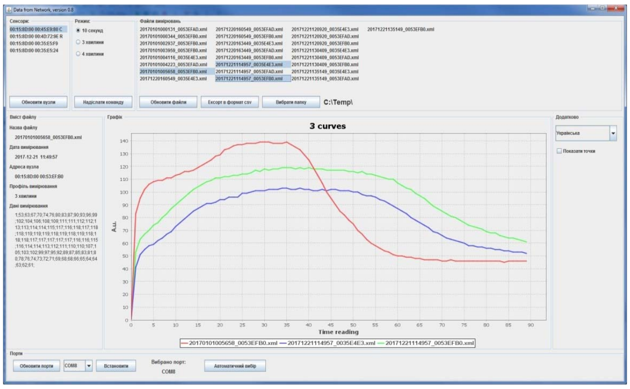

Figure 2. Main window of applied software

Main functions of applied software are following: control of ZigBee/USB converter to communicate with whole network; obtaining data about network structure; obtaining measurement data from network coordinator; storing measurement data in *.xml and *.csv formats; graphical representation of one or simultaneously several measurements; giving detailed information about separate measurement; sending commands to start measurement to all sensors or only selected one, setting operational parameters for proper network operation and measuring.

To test proper operation of WSN at first the series of experiments were conducted to determine the sensitivity of wireless sensors to influence of stressful factors of different nature on experimental plants. Tests results [6] made it possible to estimate the sensitivity of sensors to influence of stressful factors of different origin. Methodological support was developed to study not only plant state but also influence of drought, pollution, different doses of pesticide and herbicides. Obtained results make it successful to use the developed wireless smart sensors and WSN in industrial agriculture.

Working sample of the wireless network was demonstrated on International agro-industrial fair Agro-2018 and 2019, Kyiv. With aim of conducting field trials on an industrial scale one of WSN was assigned to the Institute of Bioenergy Crops and Sugar Beet NAAS of Ukraine. Also one WSN was assigned to Taiwan for equipping the smart greenhouses.

IV. WSN TESTING

The autonomy, portability, and energy-efficiency [18] are the main requirements for the network wireless sensors. The tests to detect crash operation of sensor nodes were conducted in laboratory conditions in forced mode to estimate autonomous operation of network nodes and detect errors. The sensor node contains embedded Li-Po accumulator with following technical parameters: operational voltage from 4.2V till 3.7V; 150 mAh capacity, high current of discharge; stable current of discharge in temperature range from -20°C till 60°C; long operating time; ecological safety; light weight. The measurements were conducted during one month simultaneously for four autonomous sensor nodes, integrated into the network. It was conducted 3-5 measurements of CFI curves per day, each measurement lasted 4 minutes.

Battery charge was 100% before measurements; the battery voltage was 4.2 V. During the experiment time the value of charge reduced to 29% or 3.845 V. The value is the minimum recommended threshold of discharge Li-Po batteries to obtain correct measurement results. The plot of estimating the time of autonomous operation of network nodes is shown on Fig. 3.

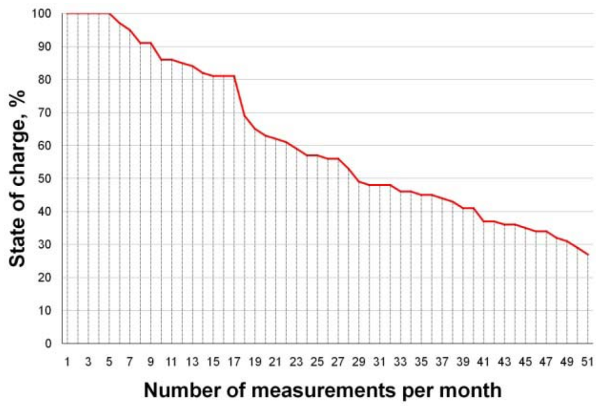

Figure 3. Plot of estimating the average time of autonomous operation of network nodes

It was found that results of the experiments differ from the modeling results [1], which demonstrated longer time of node autonomous work. It occurred because our models did not take into account the quiescent current of all microelectronic components of the sensor node.

So it was decided to adjust our model to calculate more accurate time of wireless node autonomous operation. During introducing new developed wireless nodes for environmental parameters' monitoring into our network we precised our model and got more accurate data, that corresponded to test results in laboratory conditions. Some results are described in next clause.

V. WSN UPGRADING

During implementation of WSN, intended for measuring of agricultural plants' state, it is very acute issue to integrate such networks with systems of higher level. The main aim of such integration is obtaining of data, for example, about dynamics of environment or soil parameters' changes, stages of technological processes, fertilizes or pesticide application etc. Obtained data from different systems together with measured data about plant state give possibility to make timely optimal managerial decision concerning care about agricultural plant protection.

Developed WSN includes wireless sensors for plant state measuring on the base of CFI effect. For this network upgrading it was decided to include sensors for environment parameters measuring, further data storing and dynamics of proper parameter changes generating.

First prototypes of wireless node included 3 sensors for several environment parameters' measuring: 1) soil humidity, 2) soil temperature, 3) air temperature and humidity.

Since the one of main features of network wireless node is time of battery life in field conditions, so firstly it was modeled the battery time, with taking into account the hardware particulars of such wireless node. For modeling [10, 11] it was used the improved model, which now consider power consumption of all microelectronic components of the wireless node, but not only the microprocessor and wireless units including quiescent currents. Before modelling it was measured the power consumption of wireless node on different stages of its operation, using the digital-to-analogue analyzer "LabTool" with applied software of Embedded Artists company and applied software "JN516x Customer Module Evaluation Tool". Wireless node operates from the battery with capacity of 150 mAh. Coefficient of incompleteness of discharge of battery is equal to 1.3.

Firstly the power-consumption of wireless node was measured during next 5 operational modes: wake from sleep, initialization, channel selection, clear channel assessment, and sleep. The node wakes after the sleep every 3 seconds, and checks accessibility of network and presence of data. On the whole, the average supply current during all modes was equal to 6,2 μA.

If the node needs to transmit data, then before sleep the node transmits standard data packet. The useful data content of such packet equals from 1 to 4 bytes, depending from the number of sensors in node. Standard data packet with 4 useful bytes was transmitted in 3,963 ms with supply current of 20,28 mA. In general the average supply current during this mode was equal to 32,99 μA.

In measuring mode new stage is added to mentioned above operational modes: simultaneous measuring of air and soil parameters by all three sensors. It is needed to note, that measurement time and power consumption of different sensors are different: air temperature and humidity sensor have measuring time 2 seconds with supply current of 2 mA, soil humidity sensor – 750 ms with supply current of 3 mA, and soil temperature sensor – 10 seconds with supply current of 500 μA.

According to applied task the environmental parameters are measured 1 time every 1, 5, 15, 30 minutes, 1, 2, 12 and 24 hours. Supply current during these modes, using 3 sensors for measurements, equaled 214, 63, 38, 32, 29, 28, 26,5 and 26 μA accordingly. Supply current of all other microelectronic components was changing from 10 to 25 μA, and its average value was 20 μA.

Experimental testing and modelling let to obtain the dependence of time of autonomous operation of node without battery replacement on the time between measurements (Fig. 4).

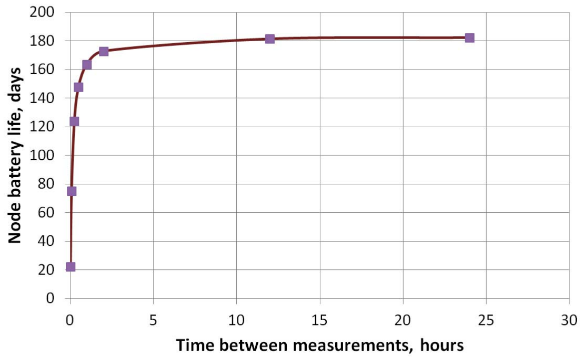

Figure 4. Schedule of estimating the time of autonomous operation of network nodes

As obtained results show, hourly measurements of environmental parameters let us to expect on 160 days of autonomous operation of the wireless node without battery replacement. But, it should be noted, in field conditions the time of autonomous operation can be decreased by such reasons, as lessening battery charge because of temperature oscillations, increasing of supply current during data transmission because of noise and obstacles etc. So, the actual time of autonomous operation of the wireless node in field conditions can be on 30% less, than value, obtained during the testing and modeling.

VI. DATA ACQUISITION AND ANALYSIS

General experience in CFI data acquisition and analysis shows that the study of CFI effect is complicated task through natural variability of plants, nonlinear dependencies of CFI from environment factors. Implementation of CFI effect in a real application requires appropriate amount of dataset, appropriate methodological support, automation of measurement. The best way to solve this problem is developing and implementing the systems that will allow acquiring data (CFI data and environmental parameters) from researchers, wireless sensor networks and other resources.

Thus, for this purposes a Web-service system was developed by authors and implemented. The system are based on small autonomous programs that exchange data by means of intranet or internet protocols (e.g. ZigBee or http-protocol) and allows processing queries from different users and acquires data from WSNs distributed on large territory.

The processing and analyzing of data, received by means of WSN, was conducted using feed forward neural networks. Neural networks allow discover whether CFI effect can be used for some applied task (for example for decision-making about necessity of watering, detection of infection on early stages, effectiveness of herbicide and fertilizer treatment, stress factor registration etc). One solved task was plant species classification on base of measured CFI curves. Neural network showed that CFI curves with duration of 5 minutes are more suitable for plant species classification than CFI curve with duration 10 seconds [6]. In this applied task the developed applied software helps users to select the optimal duration of measurement for getting more precise results to make correct managerial decision.

A second applied task was to make a decision about necessity of plant watering. Taking into account the CFI curves and air temperature the developed software, using neural network, helps users to determine optimal time for plant watering.

VII. CONCLUSIONS

The wireless sensor network for express-diagnostics of agricultural plants' state was developed to increase efficiency in decision-making in modern agriculture and can be easily integrated with technologies of precision and digital agriculture. Created hardware, software and methodological support of the wireless network can obtain data about agricultural plants' state on large territories of agricultural lands or in greenhouses, analyze them and help quickly and timely to make decision for plants' protection, stress factors' influence decreasing etc. Proposed network is implemented and tested under field conditions both in open agricultural lands in Ukraine and in smart greenhouses in Taiwan.

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