Wireless Networks of Smart Sensors and Biosensors for Express Diagnostics of Plant State and Quality Control of Beverages

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***Abstract*— Currently, smart sensors and networks based on them are widely used in all areas of human activity, including the food industry, agriculture, drug production, healthcare, environmental protection, etc. Sensor technologies are among the key modern technologies. According to IoT Analytics magazine, the global smart sensor market has grown by at least 20% in 2022. This market includes smart sensors that can operate both autonomously and as part of wireless sensor networks (WSNs). The report discusses the results of the development of WSN, obtained by a team of authors of the V.M. Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine over the past five years. The developed networks are intended for use in agriculture and food industry, namely for express diagnostics of grape plants and quality control of wine and wine materials during the production process.**

***Keywords*— wireless sensor networks, sensors, express diagnostics, plant state, wine quality.**

I. INTRODUCTION

Information and communication technologies, wireless sensor networks and technology of Internet of Things are increasingly penetrating into various areas of industry and the daily lives of ordinary citizens, including agriculture and technological processes of food and beverage quality control. Today, many projects and ready solutions in the area of data acquisition on the base of wireless technologies are aimed at application in agriculture and technological processes, since a lot of data should be acquired quickly and timely from big territories of agricultural fields, hothouses or workshops.

A detailed bibliographic analysis of the use of WSNs in various agricultural industries on the base of analysis of academic papers is given in [1]. Several practical examples of application of IoT technology and WSNs in agriculture and greenhouses are given in [2]. The integration of such technologies as WSNs and UAV-based solutions for agricultural applications are described in [3, 4]. Today WSNs and IoT tools are often used to control food or beverages quality only during storage, transportation and smart packaging, but not during production [5]. The technology of IoT is used, for example, to manage intelligent tags collecting physical parameters such as temperature and humidity as well as the location information during logistics processes [6].

The wireless networks proposed by the authors can be used both in agriculture to diagnose the state of plants and in the food industry to control the quality of food and beverages. The target application of WSN can be changed by embedding proper developed sets of sensors into wireless measuring nodes. Optical sensors based on the effect of chlorophyll fluorescence induction (CFI) were developed for express diagnostics of the state of plants [7]. To control the quality of food and beverages, multi-biosensors based on the amperometric approach have been developed [8].

The WSN for express diagnostics of plant state can be used to estimate the state of various crops, agricultural plants or fruit trees. The CFI method used makes it possible to non-invasively estimate the state of the plant by the form of the CFI curve and the characteristic points on this curve within a few minutes. This allows real-time control of artificial irrigation, fertilization of herbicides or biologically active additives. The CFI method has been used for a long time in computer devices from different manufacturers including in devices of the Floratest family (Fig. 1) developed at the Institute of Cybernetics of the NAS of Ukraine [7].

The WSN for control of quality of food and beverages is based on amperometric biosensors, which represent biomolecular electronic devices based on electrochemical

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sensors with an enzyme converter on the sensitive surface of the working electrode [9].

Fig. 1. Computer device for express diagnostics of plant state "Floratest"

II. Organization of WSN for Express Diagnostics of Plant State and Quality Control of Wine

WSN using smart sensors with a radio channel based on the CFI method is an original development of a team of authors. Structure of developed WSN is shown in Fig. 2.

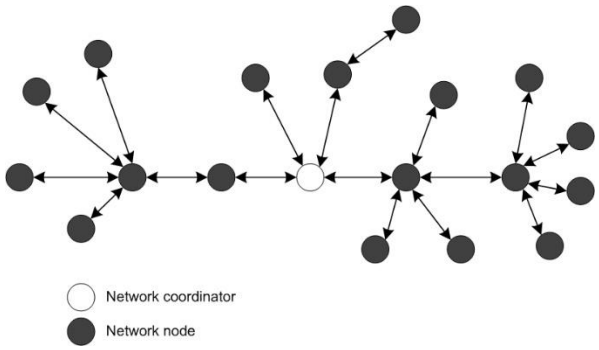

Fig. 2. Structure of developed WSN for express diagnostics of plant state

It includes wireless sensor nodes (Fig. 3) and a coordinator (Fig. 4). In addition to measuring the CFI parameters and converting them into a digital code, the smart sensor performs preliminary processing and transmission of the measured data to the network coordinator.

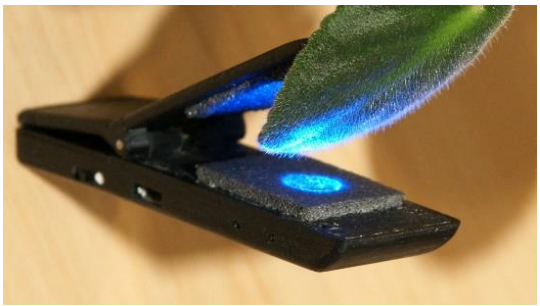

Fig. 3. Wireless sensor node based on CFI method

Network coordinator gathers data from all wireless sensor nodes, processes data to support user in decision-making and, if it is necessary, sends the processed data to the system of higher level or decision-making center [10].

Fig. 4. WSN coordinator

In accordance with the requirements of the standards, wine quality control is a rather complex and lengthy process, and wine products are subject to control after each stage of the technological process of wine production. The list of main stages includes preparation of raw materials, must fermentation, clarification of wine, its aging and others [8]. Note that the chemical composition of wine consists of aromatic substances, carbohydrates, sugars, various organic acids, ethyl alcohol, minerals and many others, all of which are normalized depending on the type of wine. Based on the number of biochemical indicators, winemakers need to have biochemical laboratories with complicated expensive equipment and qualified personnel.

The Institute of Cybernetics and Institute of Molecular Biology and Genetics of NAS of Ukraine developed a network of multisensors, which is an alternative to the biochemical laboratory. The advantages of such a network are rapidity, ease of use, automated data acquisition from all stages of wine production. In addition, these multisensors can be used directly at the consumer to control the quality of not only wine, but also juices, water and other beverages or food. An important advantage of the network is that data preprocessing is performed in the multisensor node, and only the data necessary for process control is transmitted to the network [11]. For this purpose, the measuring system on chip (SoC) ADuCM350 [12] is included in the multisensor. It contains a 16-bit ADC with a multiplexor, to which it is possible to connect up to eight amperometric biosensors. In addition, the multisensor includes a transceiver. To control the wine making process, the WSN was developed, which includes the required number of multisensor nodes, each of which contains up to eight biosensors, a network coordinator and a technologist's workplace. The network coordinator forms the network structure, maintains its continuous operation and data acquisition for transmission to the technologist's workplace. Multisensor nodes can include actuators that allow controlling technological processes without operator intervention.

III. WSN Algorithms

The above-mentioned network nodes can usually be adapted to different applied tasks through small update of applied software and reconfiguration of hardware-software interfaces and set of sensors of wireless nodes. At the same time, the hardware does not need any changes or upgrades, with the exception of rechargeable batteries, memory modules or sensors. Each of the proposed wireless nodes has a certain functional purpose, for the implementation of functions of which the appropriate applied software have been created.

The algorithm of network coordinator is intended for network organization, connection of measuring nodes, visualization data about network, measuring nodes or measuring data, and, if it is necessary, connection to a PC for data transferring. The network coordinator works independently and the presence of PC is not mandatory.

The algorithm of the wireless sensor node is responsible for its initialization, initial configuration, search for the network to which it should be connected. After connecting to the network, the sensor node receives instructions from the coordinator in accordance with the technological process or application tasks. Note that all the algorithms that control the operation of the network correspond to a specific production process according to the application software.

On the base of the proposed algorithms, there was developed applied software for network coordinator and network node, which interact with each other via special software interfaces and services during the network operation. The scheme of interaction of applied software of wireless nodes in the network is shown in Fig. 5.

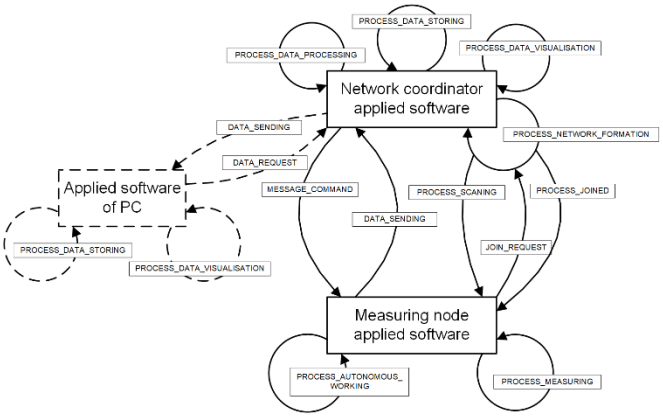

Fig. 5. The scheme of interaction of applied software of wireless nodes

IV. WSN TESTING

The developed multisensor node for quality control of beverages was tested offline. The current resolution of such node was 1 nA; the resolution in millimoles was 0.05 mmol of glucose in a 5-mL buffer solution. Some results of testing multisensor on measurements of solution concentration are shown on Fig. 6.

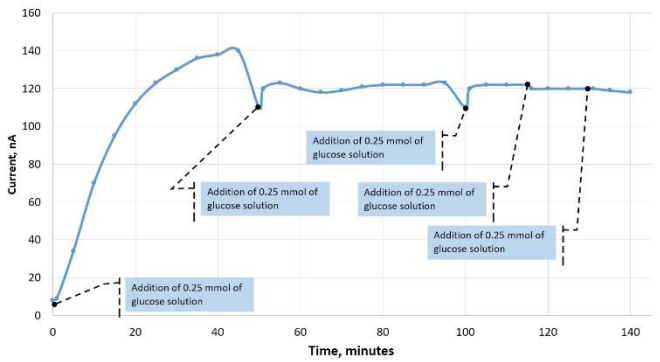

Fig. 6. The results of testing the multisensor on measurements of glucose concentration

Wireless transmission of measuring data in network was experimentally tested separately for ZigBee and Bluetooth protocols. For ZigBee protocol, the distances at which data were delivered without losses were determined. In conditions of open territory and low vegetation, the distance of guaranteed data delivery for our network was 50-70 meters.

For Bluetooth protocol, experimental testing was carried out indoors with direct visibility between the data source and the receiver. For our case, the minimum time interval between successive transmissions of data packets was 2 ms for guaranteed delivery of measuring data packets without losses.

V. CONCLUSION

As a result of the performed research and design, the following results were obtained:

1) Basic structures of wireless nodes and sensors have been developed, including functional and circuit diagrams, as well as network applied software.

2) Computer devices and WSN for express diagnostics of plant state have been brought to industrial designs, serial production and are delivered to customers.

3) Working prototypes of WSN for wine quality control with ZigBee and Bluetooth protocols have been created.

REFERENCES

[1] A. Abdollahi, K. Rejeb, A. Rejeb, M. Mostafa, S. Zailani, "Wireless Sensor Networks in Agriculture: Insights from Bibliometric Analysis", *Sustainability*, 2021, 13, 12011. https://doi.org/10.3390/su132112011.

[2] M. Lavanya, S. Srinivasan, "A survey on agriculture and greenhouse monitoring using IOT and WSN", *International Journal of Engineering & Technology*, 7(3.3):673, 2018.

[3] D. Popescu, F. Stoican, G. Stamatescu, L. Ichim, C. Dragana, "Advanced UAV–WSN System for Intelligent Monitoring in Precision Agriculture", Sensors, 2020, 20(3): 817. https://doi.org/10.3390/s20030817.

[4] J.G.A. Barbedo, "A review on the use of Unmanned Aerial Vehicles and imaging sensors for monitoring and assessing plant stresses", *Drones*, 2019, 3, 40.

[5] R. Raju, G.E. Bridges, S. Bhadra, "Wireless Passive Sensors for Food Quality Monitoring: Improving the Safety of Food Products", *IEEE Antennas and Propagation Magazine*, vol. 62, no. 5, pp. 76-89, Oct. 2020, doi: 10.1109/MAP.2020.3003216.

[6] Z. Zou, Q. Chen, Uysal, L. Zheng, "Radio frequency identification enabled wireless sensing for intelligent food logistics", *Phil. Trans. R. Soc.*, 372, 2014, 20130313. doi:10.1098/rsta.2013.0313.

[7] Yu. Kryvonos, V. Romanov, I. Galelyuka, W. Wojcik, T. Zyska, "Independent devices and wireless sensor networks for agriculture and ecological monitoring", *in book "Recent Advances in Information technology"*, CRC Press Taylor&Francs Group, A Balkema Book, 2018, pp. 105-134.

[8] V. Romanov, I. Galelyuka, O. Voronenko, O. Kovyrova, S. Dzyadevych, L. Shkotova, "Wireless smart multisensor networks for winemaking process control", *Information theories and applications*, Sofia, Bulgaria, 2019. 26 (2). P. 165–177.

[9] S. Dzyadevich, J. Schuvailo, L. Danileiko et al, "Development of amperometric enzyme biosensors based on carbon fibre microelectrode for in vivo determination of glucose, choline and acetylcholine", *Book of the 16th European Conference of Solid-State Transducers*, Prague, Czech Republics, 2002, 1159–1162.

[10] O. Palagin, V. Romanov, I. Galelyuka, V. Hrusha, O. Voronenko, "Wireless smart biosensor for sensor networks in ecological monitoring", *Proceeding of the 9th IEEE International conference on "Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications"*, IDAACS'2017, 2017, September 21–23, Bucharest, Romania, vol. 2, pp. 679–683. https://doi.org/10.1109/IDAACS.2017.8095177.

[11] V. Romanov, I. Galelyuka, O. Voronenko, O. Kovyrova, S. Dzyadevych, L. Shkotova, "Smart Sensors and Computer Devices for Agriculture, Food Production Process Control and Medicine", *Proceeding of the 29th International Conference on Computer Theory and Applications*, 2019, October 29–31, Alexandria, Egypt. P.9-13.

[12] https://www.analog.com/en/products/aducm350.html (last accessed 25.06.2023).