MULTILEVEL SENSOR NETWORKS FOR PRECISION FARMING AND ENVIRONMENTAL MONITORING

Volodymyr Romanov, Valeriya Gribova, Igor Galelyuka, Oleksandr Voronenko

Abstract: *Plants as all alive suffer from impacts of natural or anthropogenic stress factors. Creation of wireless smart biosensors and wireless sensor networks on their base for express-diagnostic of plant state on large territories under impact of stresses of different origin provides to apply managerial measures in time to decrease the negative impact of natural and anthropogenic load on the state of agricultural lands and green plantations of megalopolis, national preserves, woodlands and parklands. The applications of wireless technologies in agriculture and ecological monitoring are considered. The main aim of the multilevel sensor network is real-time data acquisition of state of plants on large territories, on-line data processing and timely decision making according to specified criteria. Multilevel sensor network has two levels. The low level is intended for plant state data acquisition and consists of several wireless sensor networks as primary data acquisition systems. The high level of multilevel sensor network works in "cloud" environment and the main purpose of this level is data storage, data analysis and managerial decision making. The main work purpose is development of low-cost wireless smart biosensors for express-diagnostics of common state of plants and creating the proper software and methodical support for integration of these wireless biosensors into wireless sensor network and multilevel sensor network for express-diagnostics of plant state on large territories, what make possible to spread the application of new information and communication technologies to industrial agriculture, ecological monitoring and environmental protection.*

Keywords: *wireless sensor network, agriculture, ecology, environmental monitoring.*

ACM Classification Keywords: *J.3 Life and Medical Sciences - Biology and Genetics*

Introduction

In modern industrial agriculture and ecological monitoring it is needed to obtain data about the real-time influence of climatic and anthropogenic stress factors on the state of the crop or agrarian plants and use special means for their protection. For protecting the plant cover of the megalopolises, national parks, woodlands or parklands similar data and means are needed too. The application of modern achievements of microelectronics, biosensors, communication and information technologies makes it possible to solve this rather complicated problem of real-time monitoring of plant state on large territories. The most perspective technology for realization of data acquisition and processing systems is wireless sensor network (WSN).

Several years ago portable computer devices of "Floratest" family were developed and prepared for full-scale production [Romanov, 2012]. The main purpose of these devices was diagnostics of plant state in real-time mode in laboratory and field conditions. Industrial precision farming and ecological monitoring are main application fields of these portable devices. But, the field testing in German and Ukrainian agrarian farms showed some restrictions during active work with "Floratest" device in the field conditions. In particular, experienced specialist had to run measurements and the one measurement, including dark adaptation, took a long time. For speedup of measurements in general it is necessary to use a large number of autonomous portable devices. To avoid these restrictions it was started development of wireless sensor network. Such approach allowed centralizing running of measurements, made with many devices, and accumulating obtained information in the control center on server. This handling lets to cover by monitoring a large territory of agricultural lands, parklands or woodlands.

There are many advantages of wireless sensor networks in different applications. It gives a lot of benefits to users in science, industry, medicine and defense. In different applications WSNs include from tens to hundreds of nodes equipped with micro power battery supplies. Taking into account the variety of the deployed environments and resource constraints on radio communication, sensing ability, calculation means and energy supply, it is a very challenging task to design optimal WSN topology and predict its performances before deployment and usage.

State of the art of WSN applications in precision agriculture and environmental monitoring was briefly considered in our paper [Palagin, 2013]. In examined papers developed systems measure different parameters of soil, plants and environment, but any system doesn't measure and process such important parameter, as plant photosynthesis, but in some described systems the leaf chlorophyll content is measured. It is well known that photosynthesis is the main process of plant life activity and if it is necessary to know the state of plants the best way is to measure photosynthesis parameters.

The work purpose is development of low-cost wireless smart biosensors for express-diagnostics of common state of plants and creating the proper software and methodical support for integration of these biosensors into wireless sensor network for express-diagnostics of plant state on large territories, what make possible to spread the application of new information and communication technologies to industrial agriculture, ecological monitoring and environmental protection, for example, for estimating of viral and bacterial load, control of influence of climatic conditions and express-diagnostics of common level of impact of stress factors of natural or anthropogenic origin on agricultural crops, green plantations of megalopolis, national preserves, woodlands and parklands.

Wireless Sensor Network and Engineering Design

Today it is impossible to imagine the precision farming technology or ecological monitoring system without such important element as decision-making and managerial decision generating system. Data from system of primary sensors, placed directly on observable objects or territories (for example, agricultural fields, parklands, woodlands gardens and etc.), can be used as basis for decision making. Quality and completeness of data acquisition determine the correctness of decision making about implementation of necessary operations for harvest increasing, costs reducing, protecting plants and fruit trees, avoiding losses of plants or harvest from influence of stress factors of natural or anthropogenic origin.

It is necessary to note, that functional possibilities of decision-making system in precision farming or environmental monitoring significantly are determined by quantity, quality and frequency of data acquisition from fields and data processing. Meteorological data, information about soil state and, not less important, information about state of plants can be referred to data, which are acquired directly on the field, forest or garden.

Therefore, acquisition of live and objective data of plant cover state in most cases is very important factor, which causes future strategy of keeping agricultural lands, trees of woodlands, parklands or gardens and proper decision making. Certainly, it would be ideal to obtain information about improvement or worsening of plant cover state beforehand, but not after the event. It lets to protect plants from losses, decrease cost of plant protection and avoid some negative influence of stress factors of different origin.

Modern achievements in microelectronics and information and communication technologies after detailed analysis show possibility of creating WSN for express-diagnostics of state of plants on large territories with using the same effect of chlorophyll fluorescence induction, on which the operation of devices of "Floratest" family is based on. Application of microsensors for measuring additional parameters of air and soil in WSN gives possibility in indirect method to measure not only the general state of plant, but also such parameters, as pesticides content in soil, water and plants, level of soil corrosion, level of pollution in air etc.

Wireless sensor network for our applied problem has to satisfy requirements to typical sensor network for application in agriculture and environmental protection. Development of WSN depends on many factors, including failure-resistance, scaling, manufacture cost, type of operational environment, topology of sensor network, hardware restrictions, data transferring model, energy consumption and etc. Schemas for initial placing of nodes of sensor network have to satisfy requirements of cost reducing of installation, removing necessary of preliminary planning of placing schemas, improving flexibility of node placing, and assisting self-organization and failure-resistance. Nodes of our wireless sensor network are deployed in static mode. Since nodes of sensor network sometimes fail because of battery discharge or physical impacts, the structure of sensor network has to change its topology very often after the sensor network has been deployed. Changes of topology cause modification of characteristics of network nodes, notably location, accessibility (because of noise, moving obstacles etc.), battery charge, failures, changing of node functions in network. It is specified possibility to include additional nodes in WSN for replacement of non-working nodes or expansion of network or network functions.

The proposed WSN covers the large territory of crop, woodlands or parklands and microelectronic sensors with radio channel are situated directly on the leaves of plants. Every sensor includes transceiver and it makes possible to join separate sensors to WSN later, after network deployment.

Development of wireless sensor network for precision farming and environmental monitoring was begun from development of certain node of such network. As base it was used typical architecture of such node, which includes several basic units: data acquisition unit, data processing unit, transceiver and supply unit [Akyildiz, 2002]. Presence of additional units depends on application task of wireless sensor network. Such units, as GPS unit, power generator and mobilizer can be considered as additional elements. Data acquisition unit, as rule, includes sensor and ADC.

Designing WSN we have to pay attention on to important aspects: in-network data handling and organization of communication between network nodes. Data handling includes development of sensor interfaces, data acquisition, data compression, and data aggregation, data processing, decision-making and report forming. Organization of communication between network nodes includes adjustment of wireless modules, network synchronization, planning MAC-protocols, topology control, strategy of network relations, and common organization of data dissemination.

For designing pilot elements of WSN it was chosen the wireless microcontroller JN5168, manufactured by NXP Company. Microcontroller includes 32-bit processor with 1–32 MHz clock speed, 2,4 GHz IEEE802.15.4 compliant transceiver, 4-input 10-bit ADC and a comprehensive mix of analogue and digital peripherals etc. This microcontroller complies with the network nodes requirements. It supports data acquisition, data storage and data transferring via wireless channel.

The standardization and unification requirements to WSN are determined by 802.15.4 standard, which defines features of creation of networks with low data throughput. In additional ZigBee and JenNet-IP protocols determine requirements to network routing and security. We selected JenNet-IP protocol for our applied tasks.

The JenNet-IP protocol combines IEEE802.15.4-based wireless network technology and the Internet Protocol (IP) to achieve integration between the two domains, supporting the wireless "Internet of

Things". Due to the nodes of a wireless network are to be controlled both wirelessly and from IP-connected device, such as a smart remotely located phone or tablet.

Topology control layer support the determination of data transfer energy consumption for certain units and type of communication of such units. As a rule, the minimum transmission delay in the network has to be reached for minimum energy consumption. Optimal selection of in-network data transfer protocol lets to get optimal ratio of above mentioned parameters.

On the initial development stages for proposed tasks it was proposed to use simple tree-like topology of WSN. The part of WSN topology, which was created as base fragment (cluster) of network, is shown on Figure 1.

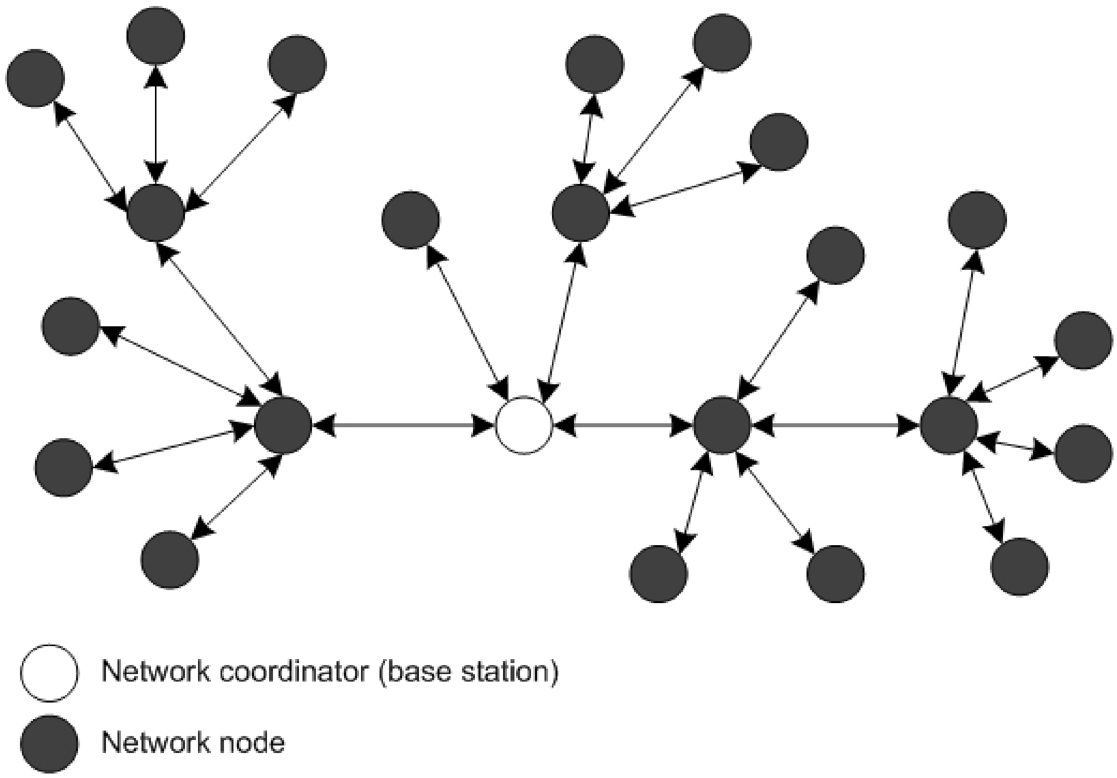

Figure 1. Fragment of WSN topology

Normally, there are two classes of nodes in developed network. The first class is the full-function node. This node can be used as coordinating node (coordinator) for separate fragment of WSN. Such coordinator realizes the communication model, which allows communicating network nodes. Also the coordinator can interact with higher level of multilevel sensor network. The second class is nodes with limited functions. That is simple nodes with micropower battery resource and low requirements to network. Normally such nodes can communicate with full-function nodes and can't serve as network coordinators. The main purpose of these nodes is acquisition of data of state of plants and data transferring. As a rule, such nodes can retransmit data from remote nodes to network coordinator.

Multilevel Sensor Network

Multilevel sensor network is intended for express-diagnostics of plant state, knowledge base filling and managerial decision making. The network include such elements: wireless sensor network or networks as primary data acquisition system, knowledge bases about current and normal (reference) states of plants, processor for managerial decision making and user interface. The schema of proposed multilevel sensor network is shown in Figure 2. Knowledge base contains information about state of different plants in normal climatic conditions, acceptable deviations of these conditions, and means for compensation of influence of external stress factors and etc. Knowledge base is filled in real-time mode with information about current changes of state of plants or trees, what were caused by stress factors of natural or anthropogenic origin. Information about plant state is formed by means of proposed above wireless sensor networks. Nodes of these WSNs are placed directly on the plant or tree leaves. Processor of multilevel network works in "cloud" environment, what improves the results of managerial decision making during fast changes of knowledge about current state of plant state because of climatic changes and anthropogenic impacts. User interface is developed as web-interface, what ensures the interaction with different types of data and knowledge and gives the possibility to adopt such interface with the user requirements.

So plant state data are passed from WSN to next level of multilevel sensor network. The managerial decision "to water or not to water", or "to fertilize or not to fertilize", "to add herbicide or not", and so on is determined with data processing. It is expected that knowledge database is permanently replenished with new data of stress factor influence to plant state, the processors of cloud system generates managerial decision in real time, and user Web-interface supports the filling knowledge database from different information providers.

Today the main elements of proposed WSN and cloud environment for precision farming and environmental monitoring are developed within two international projects. The first field tests of wireless sensor will be held in the end of this year. During this year the preliminary variant of methods for managerial decision making will be developed. Next year we plan to test whole system and the test results will be published.

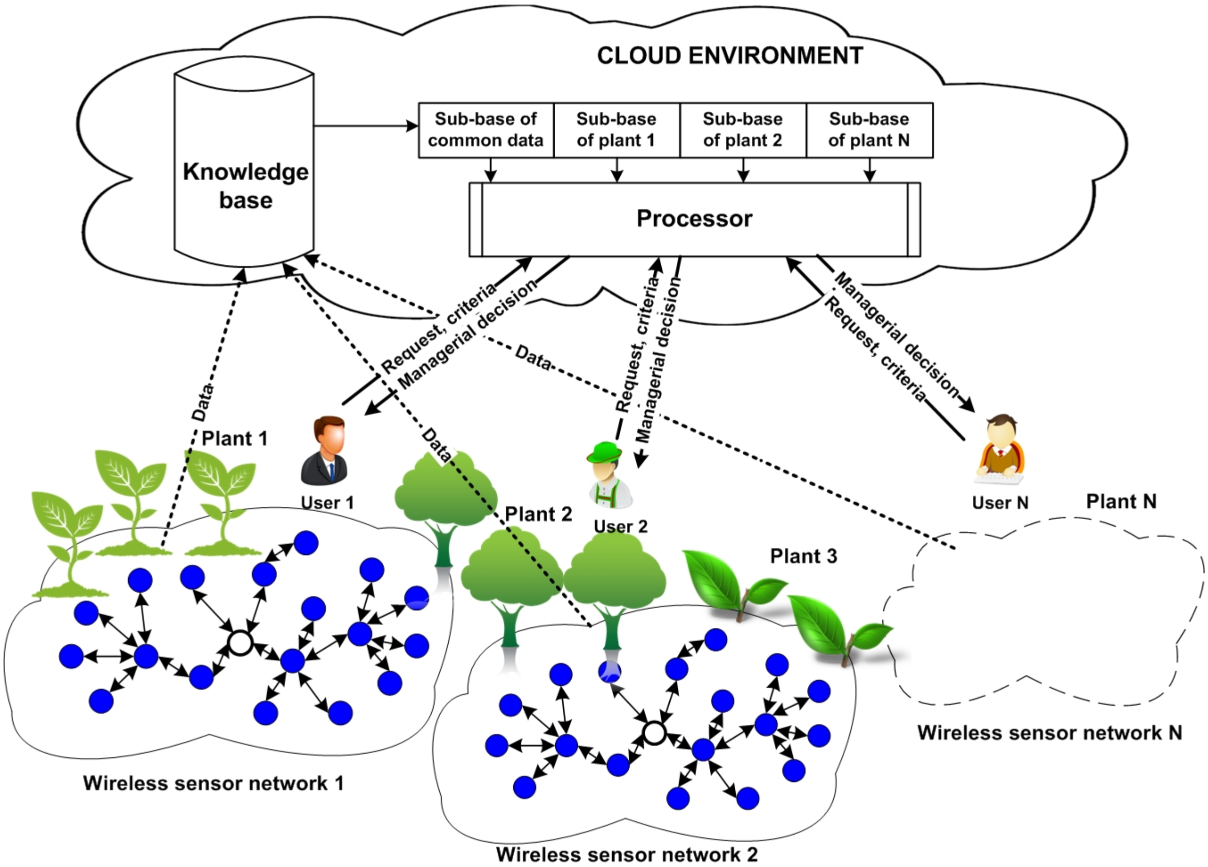

Figure 2. Schema of multilevel sensor network

Conclusion

Implementation of proposed multilevel sensor network and wireless sensor networks to industrial agriculture, environment protection and ecological monitoring makes it possible to increase efficiency and quality of agricultural products, spare fertilizers, water and energy resources, timely protect agricultural plants, woodlands and parklands from infections and anthropogenic impacts.

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Authors' Information

Volodymyr Romanov *– Head of department of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine, Doctor of engineering sciences, professor; Prospect Akademika Glushkova 40, Kiev–187, 03680, Ukraine; e-mail: VRomanov@i.ua; website: http://www.dasd.com.ua*

Valeriya Gribova – *Head of Intelligent system laboratory of The Institute of Automation and Control Processes of Far eastern branch of Russian academy of sciences, Doctor of engineering sciences, professor; Radio str., 5, Vladivostok, 690041, Russian Federation; e-mail: gribova@iacp.dvo.ru*

Igor Galelyuka *– Senior research fellow of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine; Candidate of engineering sciences; Prospect Akademika Glushkova 40, Kiev–187, 03680, Ukraine; e-mail: galelyuka@gmail.com; website: http://www.dasd.com.ua*

Oleksandr Voronenko *– research fellow of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine; Prospect Akademika Glushkova 40, Kiev–187, 03680, Ukraine; e-mail: alexander.voronenko@dci.kiev.ua; website: http://www.dasd.com.ua*