WIRELESS SENSOR NETWORK FOR PRECISION FARMING AND ENVIRONMENTAL PROTECTION

Oleksandr Palagin, Volodymyr Romanov, Igor Galelyuka, Oleksandr Voronenko, Yuriy Brayko, Roza Imamutdinova

***Abstract**: Climate changing, anthropogenic disasters and fast spreading of viral and bacterial diseases of plants in agriculture, gardening, forestry indicates necessity to develop and full-scale production of sensor tools for express-diagnostics of plant state in real-time mode and estimating influence level of climatic changes, viral and bacterial load, and stress factors of natural and anthropogenic origin on the plants. Operating objective data about plant cover state in most cases is very important factor, which causes future strategy of keeping parklands and woodlands and proper decision making in ecological monitoring and environmental protection. For this purpose smart system of environmental monitoring based on two level wireless sensor network was proposed. Smart wireless sensors, coordinator, and concentrator as the units of the wireless sensor network, and their features, and performances are considered. Architecture of wireless sensor network, structure of applied software, and testing operation of the smart sensor network are examined.*

***Keywords**: wireless sensor network, smart sensor, coordinator, information technology.*

***ACM Classification Keywords**: H.4 Information system application*

Introduction

Unforeseen changes of climate, anthropogenic disasters and fast spreading of epidemiological viral and bacterial diseases of green plantations and agricultural plants demonstrated acute necessity to develop and full-scale production of sensor tools for express-diagnostics of plant state in real-time mode and estimating influence level of climatic changes, viral and bacterial load, stress factors of natural and anthropogenic origin on the plants.

Therefore, acquisition of live (real-time) and objective data about plant cover state in most cases is very important factor, which causes future strategy of keeping parklands and woodlands and proper decision making in ecological monitoring and environmental protection. Certainly, it would be ideal to obtain information about improvement or worsening of state of parklands or woodlands beforehand, but not after the event. It lets to avoid increasing costs on environmental protection and save plants and trees from possible loss, and also to help protect plants and trees of parklands and woodlands from viral and bacterial diseases.

In Glushkov' Institute of Cybernetics of NAS of Ukraine it was designed wireless sensor network, including wireless smart sensors, network coordinators, and concentrator. The network was tested in laboratory and field conditions and test results were examined. Hardware and software and corresponding data formats for data acquisition from wireless sensor network with unmanned aerial vehicle were developed.

Work objectives

Work objectives are development, application and testing of wireless technologies in ecological monitoring, environmental protection and precision farming.

Network of wireless smart sensors

Completion of development and manufacturing of wireless smart sensors, network coordinating nodes, network concentrator and unmanned aerial vehicle with wireless data acquisition unit made it possible to define very clearly the structure of developed network of wireless smart sensors (Fig. 1). Figure also contains the photos of real samples of wireless smart sensors, coordinating node and network concentrator.

Wireless sensors are the main network elements. The main function of wireless sensor is estimating the state of plant and further transmission of measuring data to coordinating node. Sensors measure the curve of chlorophyll fluorescence induction and store last 100 measurements in internal memory. In addition the smart sensor checks the presence of wireless connection with network coordinating node, level of battery charge and volume of free memory and, in the case of contingency, records the proper information to event log.

Network coordinating node is intended for data acquisition from smart sensors, data storing and preparation of acquired data for transmitting to user. Also, coordinating node supports the network operation, including the monitoring the functionality of smart sensors, removing the collisions during simultaneous data transmitting from several sensors, managing the measurements and informing user about state of individual sensors and network in whole.

User can acquire measuring data in one of two ways. The first way provides, that user has to apply the network concentrator, which is the protected specialized mobile computer. It is enough to approach on the distance of stable wireless connection with coordinating node of network of smart sensors. So, the coordinating node transmits all measurements to network concentrator, where the user has possibility quickly and easily to review the data and, in the case of necessity, to correct the operation of sensors or network coordinating node. In addition, the concentrator gives the possibility to run the momentary measurement of state of plants by one or all sensors.

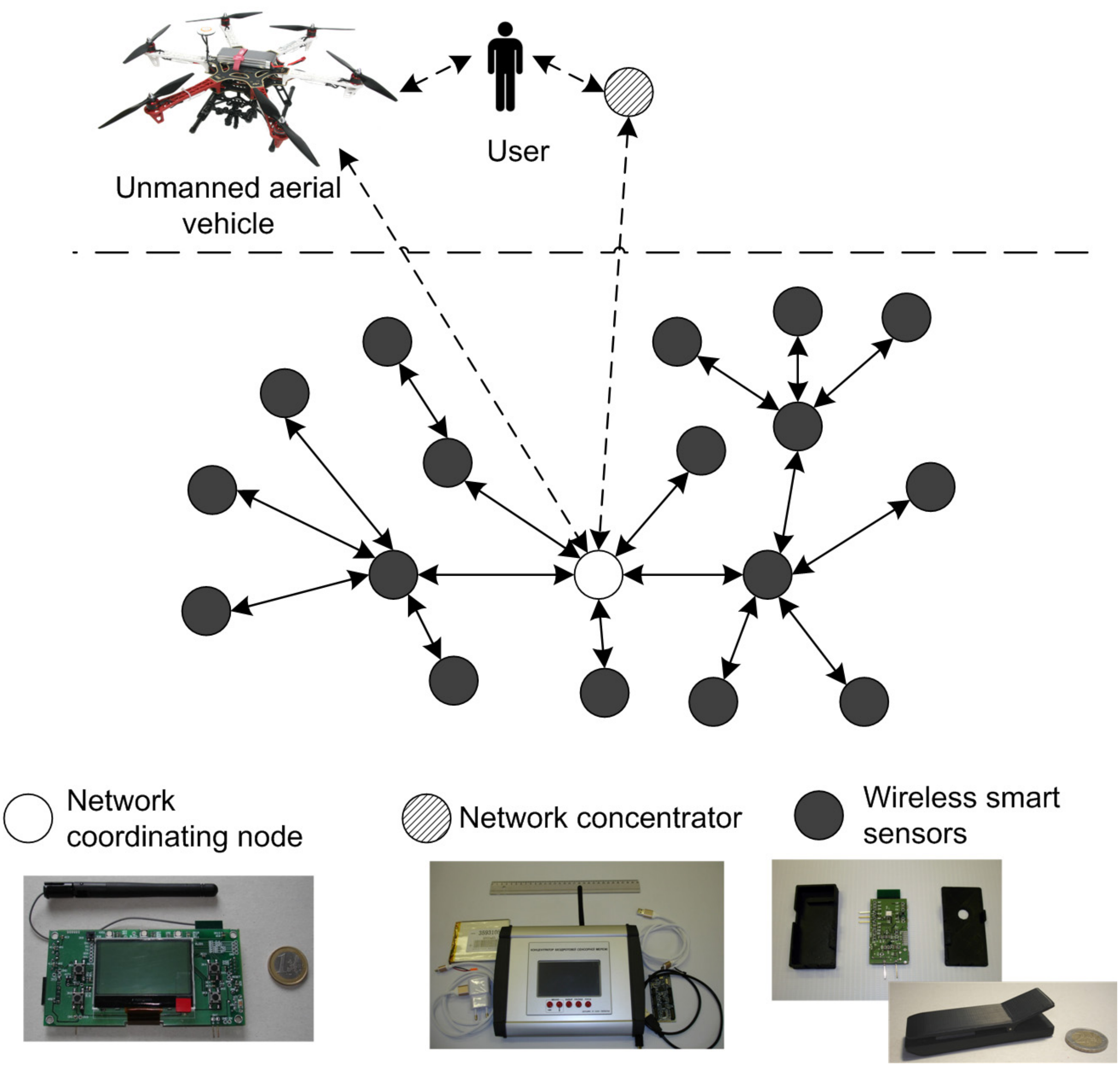


Fig. 1. Structure of network of wireless smart sensors

The second way of data acquisition may be used by user in the case, when access to network coordinating node is complicated or network coordinating node is far away from user. In this case all measuring data are acquired by unmanned aerial vehicle (hexacopter), which contains the wireless data acquisition unit with flash-memory. User inputs GPS-coordinates in flight controller of unmanned aerial vehicle, which flies to destination point and in wireless mode acquires all measuring data and event logs.

The main technical features of the smart wireless sensor are following: protection from exposure to environmental conditions at operating in real conditions; the long battery life without battery replacement or maintenance; low cost; low weight and dimensions; self-testing and self-calibration possibility for internal sensor parts; high reliability; optimum ratio between wireless data range and energy consumption; standardization and interchangeability for using electronic components; batteries replacement or charging possibility in the actual operating conditions.

The main elements that determine device functionality are wireless module and management/calculation module. The wireless microcontroller embedded into sensor significantly reduces energy consumption due to that only one microcontroller carries wireless data management, performs pre-processing of the measured data and controls input/output ports too. In addition to this approach it was applied only one software platform for the one microcontroller that in some cases significantly reduces and avoids conflicts in software. The other important hardware modules in the sensor architecture are: module which operates with biological object and power unit. The module operated with biological object would performs as the impact on biological object (irradiation leaf plants in the blue range of the spectrum) and measures the response of biological object (radiation of leaf plants in the red zone of the spectrum) on the outside influence. Power unit provides power to the all sensor's elements and enables the battery charging or replacement. Software architecture is single software application for wireless microcontrollers supported wireless data, controls and obtains measurement data from a biology object, preliminary process of measured data to storage and archiving data. The smart wireless sensor block diagram is in Fig. 2. Wireless microcontroller provides the sensor's operating, data transmission and interaction with other elements of the designed network. Since the sensor is a portable device, includes an internal battery with capacity ensured its autonomic operation for the time specified by technical requirements.

Smart wireless sensor makes it possible: to detect atmospheric air, water and soil pollutions with pesticides, heavy metals and industrial emissions; to estimate life activity of the plants after drought, frost, inoculation, pesticide application; to determine optimal dozes of chemical fertilizing and biological additions; to conduct researches in the areas of ecology and physiology of plants. Wireless smart sensor has the opportunity to operate off-line or within the network of wireless sensors. Working conditions of wireless smart sensor are following: temperature of ambient environment: from 5 till 45 ºC; relative humidity: 95% at 25 ºC; atmospheric pressure: from 84 till 107 kPa (from 630 till 800 mmHg). Technical characteristics of wireless smart sensor are following: mass of sensor: 0,03 kg; overall dimensions: 87×28×20 mm; maximum level of irradiation of leaf of living plant: 200 klux; the level of irradiation can be adjusted by coordinating node: from 50 klux to 200 klux; spectral characteristic of irradiation light: 460–480 nm; spectral characteristic of IR sensor at the level 0,5: 680–930 nm; spectral characteristic of IR sensor at the level 0,2: 550–1000 nm; irradiation area: 100 mm^2, but it is possible to increase the area according to the user requirement.

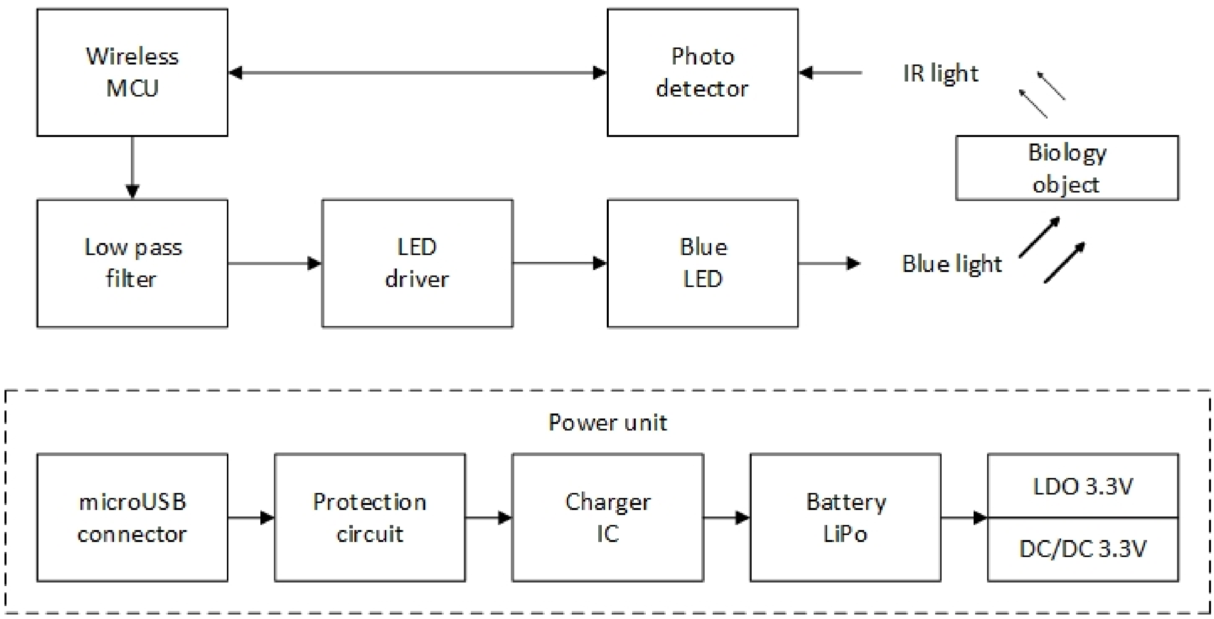
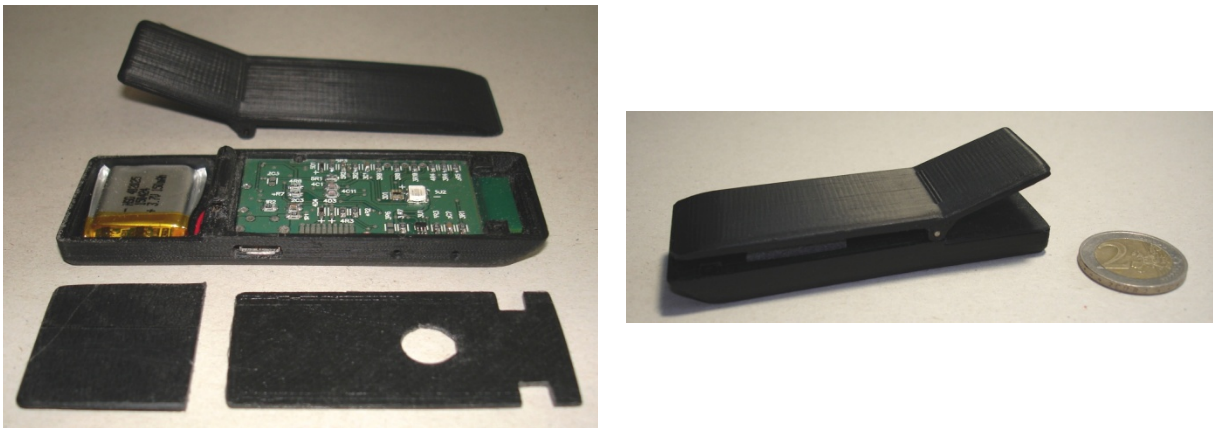


Fig. 2. Block diagram the smart wireless sensor

Assembled and disassembled wireless smart sensors are shown in Fig. 3.



a) b)

Fig. 3. Disassembled (a) and assembled (b) wireless smart sensors

Additional functions of sensor are following: self-testing and self-calibration; control of sensor parameters in process of operating or according to the requirement of network coordinating node; measuring and control of sensor battery charging; changing emission intensity; control of emission intensity.

Performances of power supply are following: sensor includes internal lithium-pol. battery with capacity: 120–200 mAh; maximum current consumption of sensor: 50 mA; battery charging is running from external power supply from 4,3 V till 6 V through connector "microUSB"; charging current of the internal battery: 75 mA; charging time till the level 95% is approximately 2 hours; charging internal battery is running from external power supply of PowerBank, Laptop, AC/DC Adaptor through "microUSB" connector, charging voltage: 5 V–5,2 V, charging current: NLE 100 mA.

Sensor has the opportunity to receive and to transmit data if the internal battery charge is low for measuring. In process of measuring chlorophyll fluorescence induction curve the sensor measures the ambient temperature and store the temperature measuring data.

Initial time of measurement and measurement modes of chlorophyll fluorescence induction curve are initialized with coordinating node of network of sensors. The measurement modes of chlorophyll fluorescence induction curve are following: the mode of OJIP test; a preset programmed modes: 1 second, 10 seconds, 3 minutes, 4 minutes; user mode – measurement parameters are programmed by user.

It is clear, that for one user it is impossible to manually operate a large quantity of wireless sensors, which conduct simultaneous measurements in certain territory. It is necessary to introduce additional facility for joining all wireless sensors into some network for acquisition and storage of measuring data. Such facility undertakes all functions of supporting the operation of network of sensors. As additional facility it was designed and manufactured coordinating node of network for operating several of wireless sensors. The main functions of coordinating node are following: joining wireless smart sensors into network, supporting operation of the network of sensors, diagnostics of state of individual sensors and network of sensors in whole, detecting unforeseen contingencies and informing user; measuring data acquisition from all sensors and data storing; controlling the measurement process of all or selected sensors according to preset user program. The block diagram of coordinating node is shown in Fig. 4.

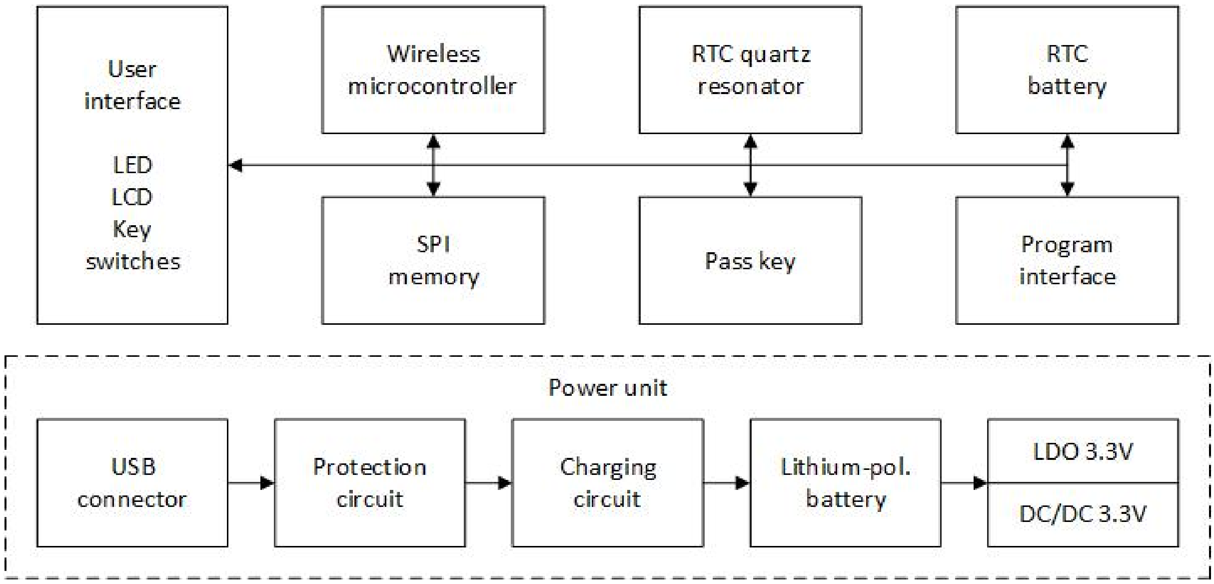


Fig. 4. Block diagram of coordinating node of network of wireless sensors

The assembled coordinator with microelectronic components is shown in Fig. 5.

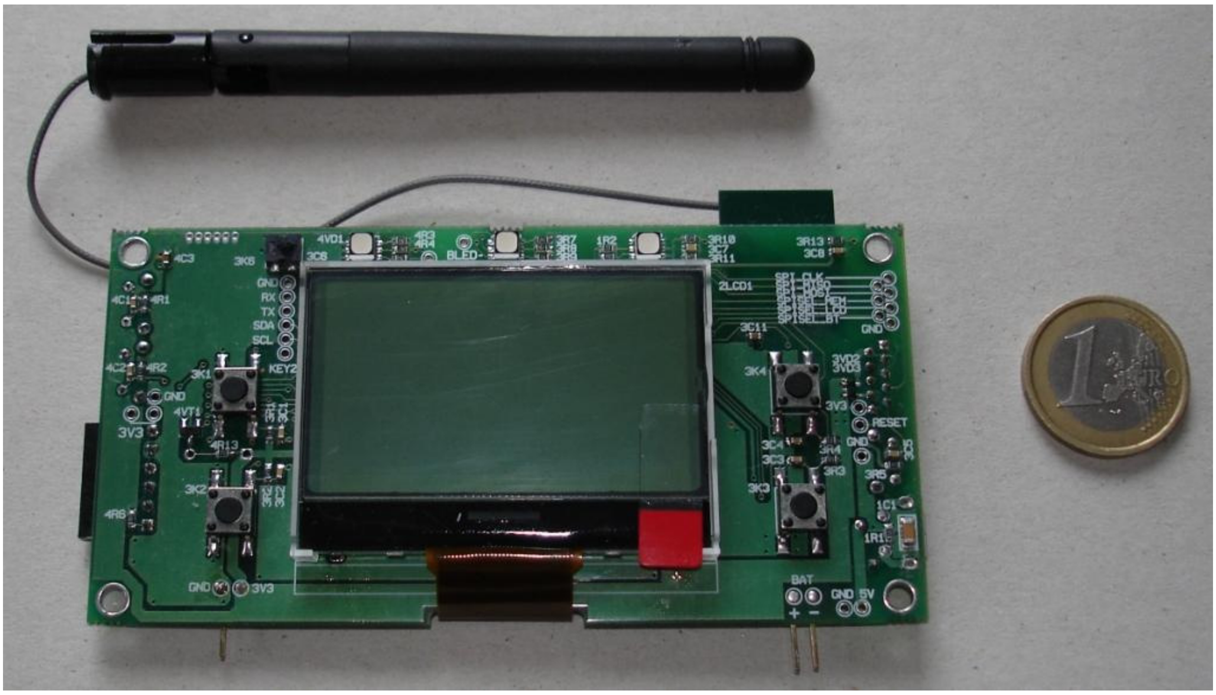


Fig. 5. Coordinating node

The block diagram of concentrator of network of wireless sensors is shown in Fig. 6. According to the diagram the concentrator includes the following units: microcontroller unit; visualisation unit (LCD); interface unit; control unit; wireless unit; debugger; DC-DC converter; charger; LiPo battery; adapter.

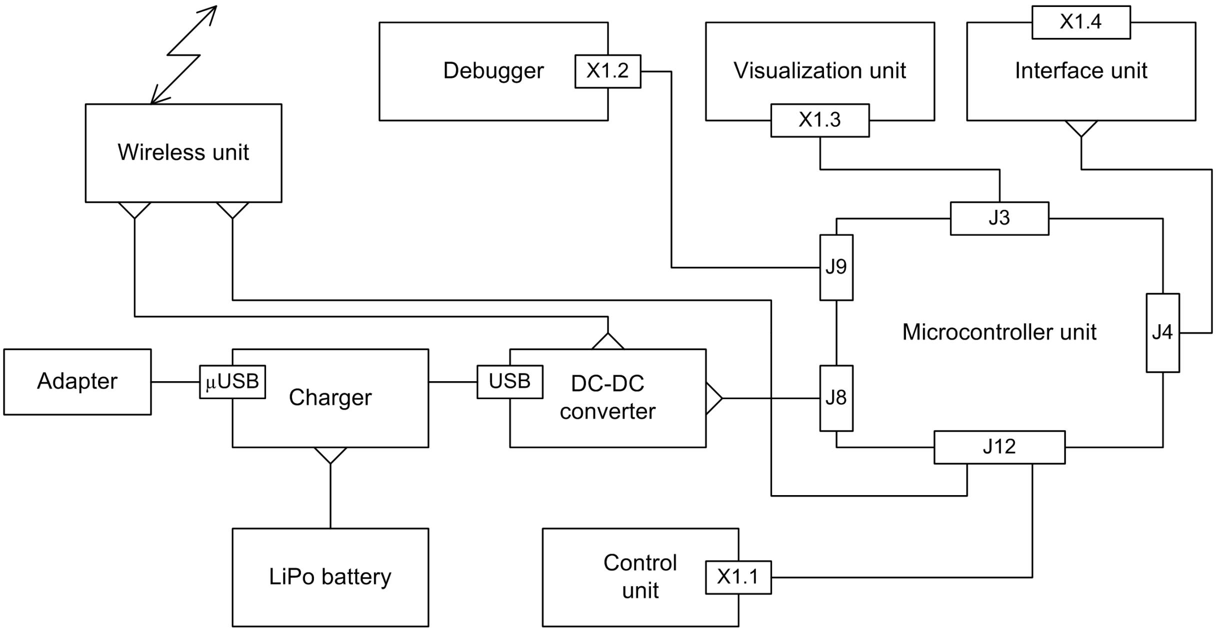


Fig. 6. The block diagram of concentrator of network of wireless sensors

The microcontroller unit is based on LPC4357. The microcontroller is intended for data acquisition, data processing, data storage and visualization of measuring data, receiving and transmitting the service information about the state of sensors and network to personal computer. The visualisation unit consists of liquid-crystal display (LCD) and serves to display the menu items and measuring data in form that is suitable for express-analysis. The interface unit is intended to connect the microcontroller unit to PC for further processing, archiving and visualization of the received information in tabular or graphical form. Control unit is designed to convert pressing of keys into signals for microcontroller. Wireless unit is based on the JN5168 microcontroller with low power consumption. This microcontroller contains a wireless module, which operates at a clock frequency of 2.4 GHz in accordance with the standard IEEE 802.15.4 (ZigBee PRO Stack). Wireless unit is used for the formation, transmission and reception of data packets from network of wireless sensors. LPC-Link2 debugger is a versatile standalone debug device, which can be connected to a microcontroller unit and supports a broad set of debugging tools and integrated development environment. Debugger is connected to concentrator, when it is necessary to reprogram and adjust the microcontroller. DC-DC converter is designed to convert the lithium-polymer battery voltage (3,7 V) in the power supply voltage of the microcontroller unit (5,0 V) with maximum current consumption of 0,5 A. The charger is used to charge the battery. Charging the LiPo battery is carried out through micro USB connector, located on the rear panel of concentrator. The charger includes protection scheme, by which the battery voltage is controlled to prevent excessive battery charging or discharging. The charger is attached to the battery and DC-DC - converter by means of cables and USB-connector. The adapter is used to convert AC 220 V to DC 5V output voltage, which is necessary for the charger operation. The concentrator of network was created as a standalone device according to modular principle. Dimensions of profile are 181,2×53,2×200 mm. The concentrator is shown in Fig. 7, and disassembled concentrator is shown in Fig. 8

Fig. 7. Concentrator of network of sensors

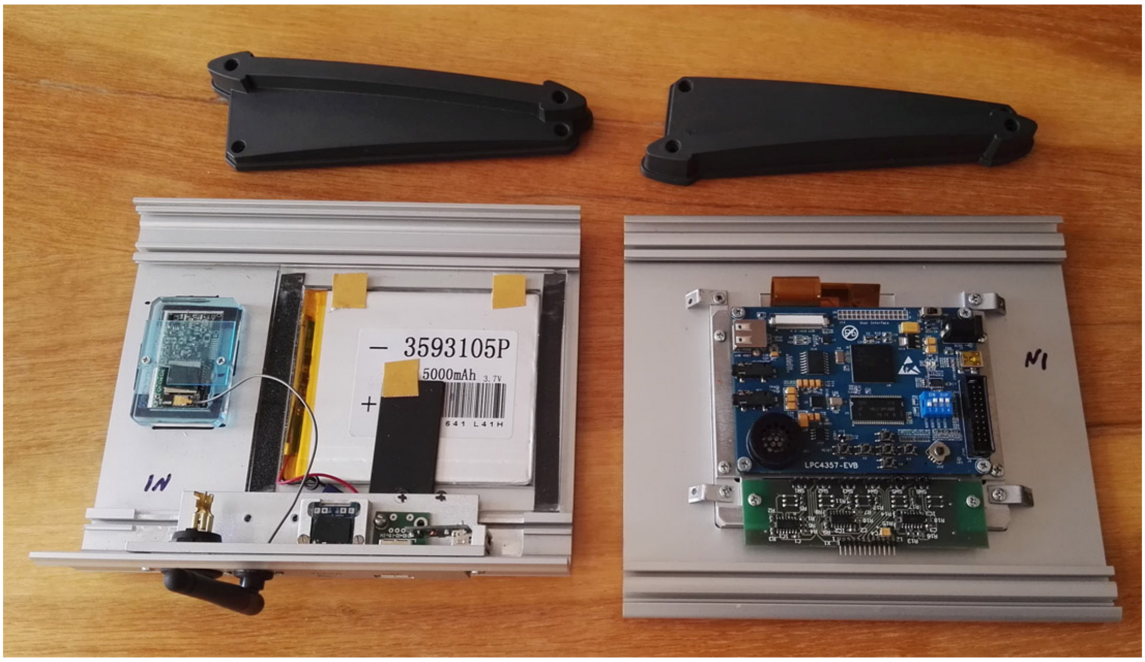


Fig. 8. Disassembled concentrator of network of sensors

LCD display FS-K430WQC-V3-F, based on graphics controller SSD1963, is included in the visualization block to display measuring data and service information. For user convenience the display has diagonal of 11 cm with 480 x 272 pixels resolution. The number of displayed colors is 16 700. The display has low power consumption, and typical current consumption is equal to 15 mA. On front panel of concentrator there are display of visualization unit and five buttons of control unit: MENU (right), MENU (down), SELECT, BACK, START, which are intended to navigate menu.

Proper applied software was developed for every hardware component of network in accordance with developed structure. Structure of developed software and interaction of program modules are shown on Fig. 9.

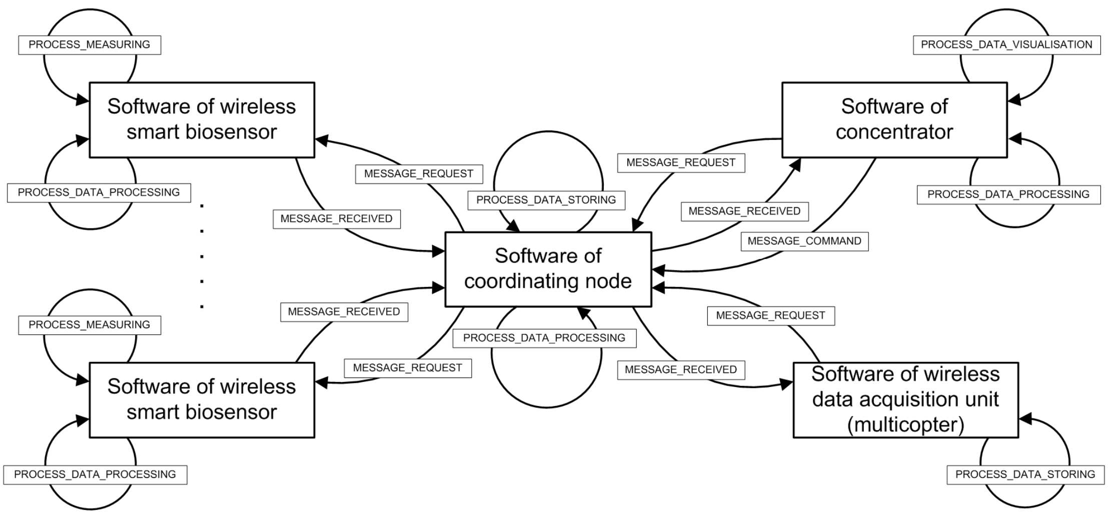


Fig. 9. Structure of applied software of network of wireless smart sensors

Applied software of wireless smart sensor ensures continuous running of sensor in autonomous power-saving mode in field conditions and provides the next functions: searching the network coordinating node and connecting to network; measuring the curve of chlorophyll fluorescence induction of plant and storing measuring data; storing the preset number of measurements; recurring diagnostics of its state, level of battery charge, volume of free memory, detection of unforeseen events and logging; preparing the measuring data and event log for transmission; transmission of data on request of coordinating node; conducting the preset measurement program or instantaneous measurement on request of user.

After manufacture of the units of wireless sensor networks they were tested in laboratory and field conditions. Main attention was paid to reliability of sensor operation in field conditions and stability of wireless data transfer channel in different conditions of environment. Data, obtained during analysis of test results, were compared with modeling results. At the first, it was tested the reliability of message transferring or, in another words, the quality of wireless channel between wireless sensors and network coordinating node. Tests were conducted for different conditions of environment, which were interesting for prospective customers. There were 4 types of environment during testing: open territory, where there was line of sight between signal source and signal receiver; low vegetation, grass, many bushes; dense vegetation, many high trees, line of sight between signal source and signal receiver was absent in most cases; urban territory, line of sight between signal source and signal receiver was absent. The results of testing are presented in Fig. 10.

For second type of testing of parameters of wireless smart sensors in laboratory conditions it was used applied software "JN516x Customer Module Evaluation Tool", which is delivered by NXP Company for testing its wireless microcontrollers, and digital-to-analogue analyzer "LabTool" with proper applied software. This testing was conducted in laboratory conditions for estimating real time, which wireless sensor spends for data transmission. This time, to some extent, defines the time of autonomous operation of wireless sensor without battery replacement. Internal timer of JN5168 microcontroller determined the time of wake-up of module and time of receiving of acknowledgment of successful transmission of one data frame. There were transmitted data frames, payloads of which was divisible 114 bytes. Ten measurements of time were made for every data package size and then average time was calculated for these 10 values. Dependence of experimental average time of transmission of data packages on data package size are shown together with calculated values in Fig. 11.

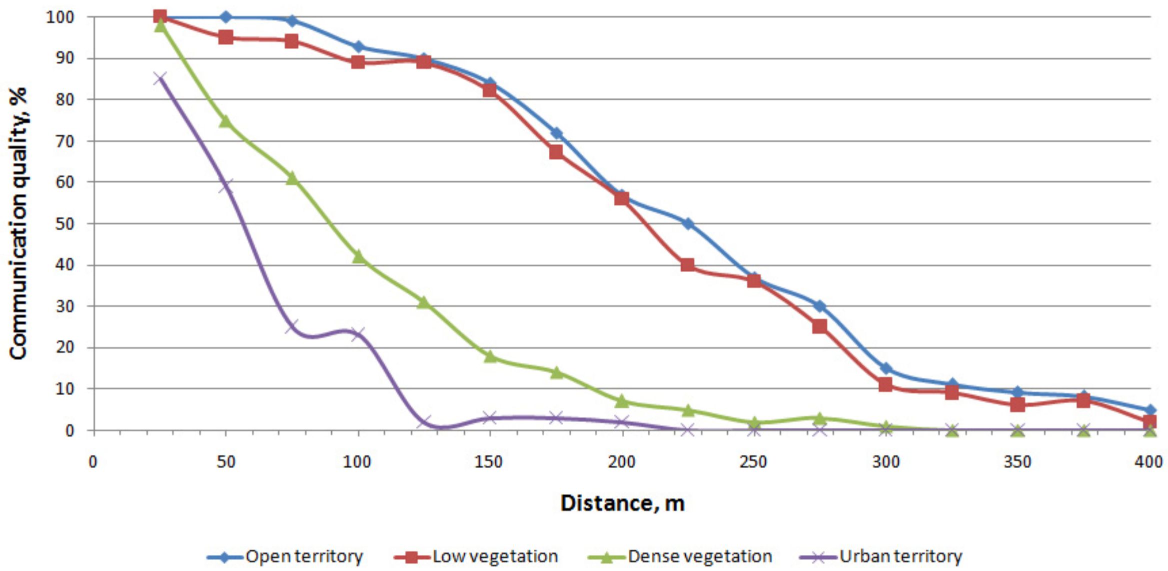


Fig. 10. Dependence of communication quality on distance between signal source and signal receiver

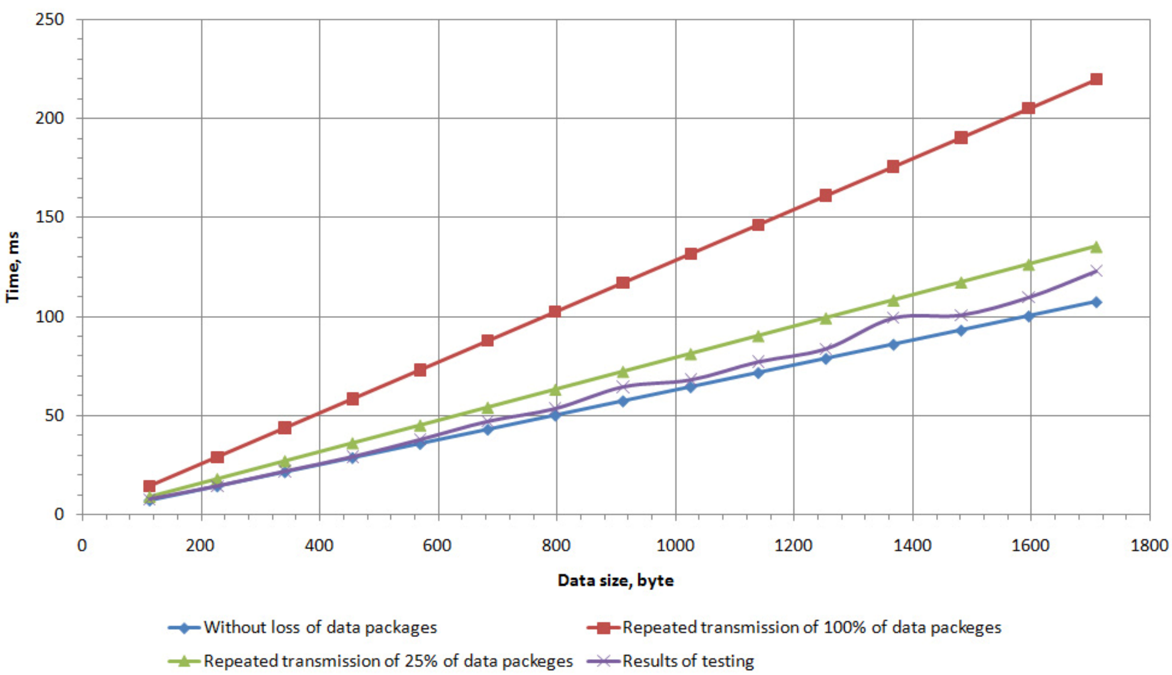


Fig. 11. Dependence of transmission time of data package on data package size

The next testing was conducted to estimate the operation time of wireless sensors in autonomous mode without battery replacement. Sensor is in sleep mode most of time. One time per three seconds the sensor wakes from sleep and checks the accessibility of wireless network and presence of commands from coordinating node. After waking-up the sensor initializes its hardware and program modules. If network is accessible and command buffer is empty, the sensor again falls asleep. If command buffer contains commands from coordinating node, the sensor measures the plant state or diagnoses the wireless channel state, level of battery charge and volume of free memory. If sensor operates according to preset user program, the plant state is measured in defined time and measuring data are transmitted to coordinating node. Measurement of power-consumption of sensor on every stage of its operation was conducted by means of software tool "JN516x Customer Module Evaluation Tool" and digital-to-analogue analyzer "LabTool" with proper applied software. Wireless smart sensor operates from the battery with capacity of 200 mAh. Packert exponent or, in another words, coefficient of incompleteness of discharge of battery is equal to 1,3. First of all, the measurement of power-consumption of sensor was conducted for next operational modes "Wake from sleep – initialization – channel selection – clear channel assessment – sleep". We obtained the next results: wake from sleep: supply current – 4,98 mA, period – 0,83 ms; initialization: supply current – 5 mA, period – 1 ms;c channel selection: supply current – 5,16 mA, period – 0,96 ms; clear channel assessment: supply current – 20,28 mA, period – 0,128 ms; sleep: supply current – 0,00064 mA, period – 180 000 ms.

On the whole, the average supply current during all modes was equal to 6,21 μA. In such mode without conducting any measurements the wireless sensor can operate for more than 2,5 years without battery replacement.

In measuring mode two new modes is added to mentioned above operational modes: measuring and data transmission. It should be noted, that measurement can last 1 second, 10 seconds, 3 or 4 minutes on user choice. Also, it can be conducted one or several measurement per day, or one measurement per several days. Testing showed, that supply current, needed for measurement, was equal to 25 mA. For example, for one measurement during 10 seconds per day the average supply current during 24 hours was equal to 9,1 μA, and for one measurement during 3 minutes per day – 58 μA. Then by using the calculation it was estimated the time of autonomous operation of sensor for certain number of measurements per day. Experimental testing and calculations let to obtain the dependence of time of autonomous operation of sensor without battery replacement on number of measurements per day. The results of testing are shown in Fig. 12.

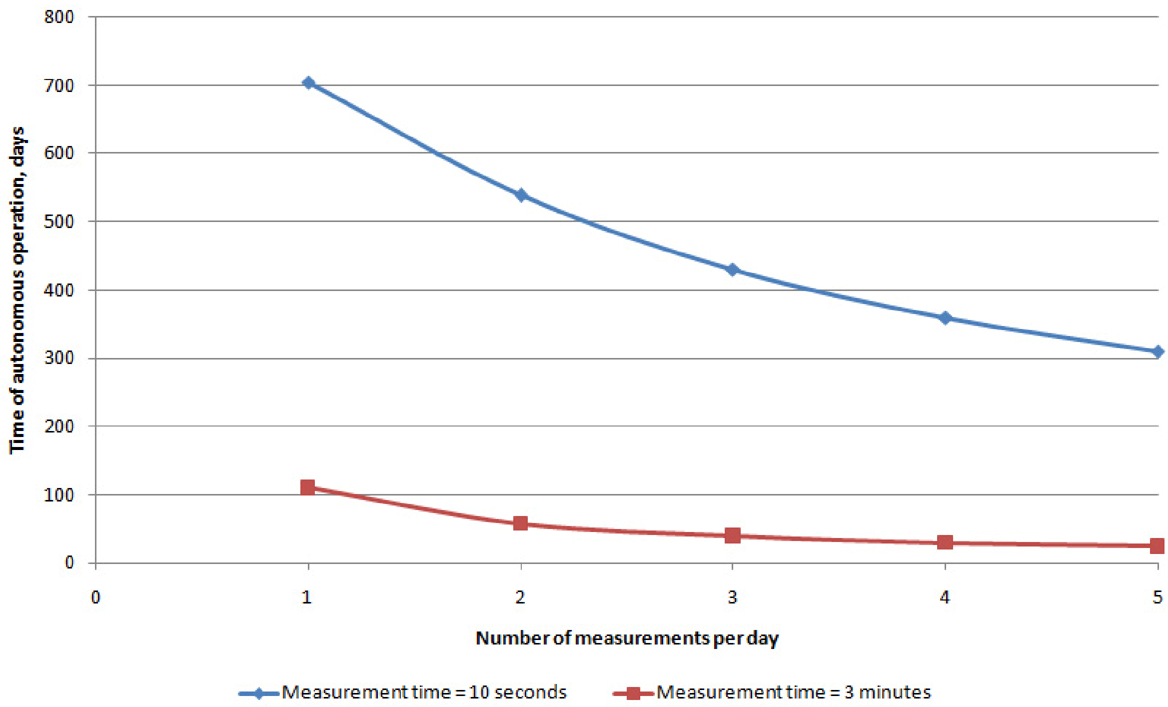


Fig. 12. Dependence of time of autonomous operation of sensor without battery replacement on number of measurements per day

Development and assembly of unmanned aerial vehicle (in our case this is hexacopter) with wireless data acquisition unit consists of 3 stages: assembly and adjustment of hexacopter, including adjustment and programming the flight controller together with GPS-unit and compass; development and manufacture of hardware of wireless data acquisition unit; development of software of wireless data acquisition unit.

The hexacopter on the basis of chassis "DJI F550" and engines "DJI 2212" was chosen for the second level of network. Controller "DJI NAZA-M V2" with GPS-unit and compass was chosen as flight controller. Ready-assembled hexacopter is shown on Fig. 13.

For using hexacopter in the area of ecological monitoring and environmental protection it is necessary to ensure the flight to preset GPS-coordinates in automatic mode and then returning home. In another words, the hexacopter has to fly to point with GPS-coordinates, where the network coordinating node is situated, acquire measuring data and return home. Setting flight route by means of GPS-coordinates is fulfilled in any special third-party software.

Fig. 13. Ready-assembled unmanned aerial vehicle

The wireless unit of developed sensor with limited functionality was used as basis of hardware of wireless data acquisition unit for hexacopter. There are main functions of wireless data acquisition unit: establishing connection with pre-given network during flight at distance, enough for stable wireless connection; sending request to coordinating node for data transmission; receiving all data from coordinating node and storing them in internal memory. Appearance of developed wireless data acquisition unit is shown on Fig. 14. On the left side of photo one can see USB-connector to transfer data to personal computer, on the right side – antenna for establishing wireless communication.

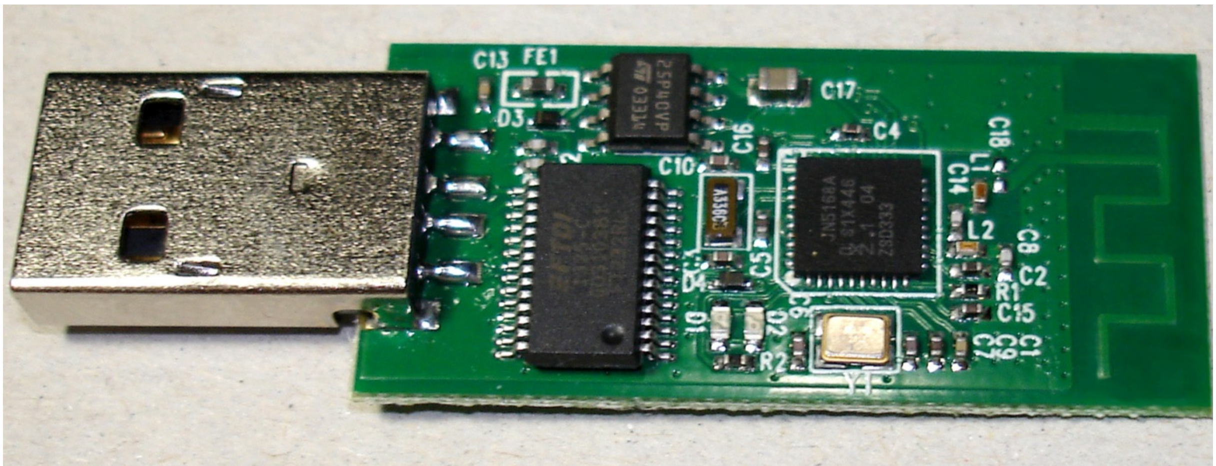


Fig. 14. Wireless data acquisition unit

Conclusion

During STCU project # 6064 "Developing and full-scale production preparing of distributed smart biosensors for environmental protection" it was designed and manufactured two-level network of wireless sensors included wireless smart sensors, coordinating and concentrating nodes with applied and testing software and mobile platform based on unmanned aerial vehicle such as hexacopter.

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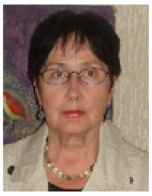

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