NEW WIRELESS SENSOR NETWORK TECHNOLOGY FOR PRECISION AGRICULTURE

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Abstract: Institute of Mathematics and Computer Science (IMCS) of the University of Latvia is implementing the project "Development of Long Range Wireless sensor network for precision farming applications in Latvia" (The Project). The Project has two main directions of research. The first is development of new long range Wireless Sensor Network (WSN) nodes providing radio link in a long distances (more than 300m), the second is development of energy efficient operating system (FarmOS) for large scale WSNs with main focus on robust easy to use agricultural applications.

Development of current WSN nodes is based on Texas Instrument's hardware and AgroSeNET technology drafted by Cominfo Inc. FarmOS is being developed in cooperation with Institute of Electronics and Computer Science.

In framework of the Project IMCS is implementing field trial of large scale Long Range WSN technology for automated radiation frost protection of cranberry fields. FarmOS supports mash topology of WSN. For small networks star and multihop topologies could be used.

The main goal of the Project is to build WSN prototype with newly designed 50 long range nodes running FarmOS to provide automated cranberry field protection with intelligent radiation frost prediction and decision making features. Depending on data gathered in the real time the intelligence of the system will provide immediate decision whether fog generator, water spryer system or just wind blowers would be chosen.

Farmer's end user client software will deliver Software as a Service concept.

Keywords: Wireless sensor networks, Precision Farming, OGC, INSPIRE, Environmental monitoring.

Introduction

Global climate changes. Fossil fuel, extensive land use, and agriculture are three main causes of the increase of greenhouse gases observed over the past 250 years. Intergovernmental Panel on Climate Change (IPCC) agreed that about 25% of carbon dioxide emissions are produced by agricultural sources, deforestation, use of fossil fuel-based fertilizers, and burning of biomass. Conventional tillage and fertilizer application release about 70% of the nitrous oxide emissions. On one hand over the past centuries substantial increase in crop yield is achieved with development of technologies on the other hand intensive agricultural methods have detrimental effects on the environment (Agriculture, 2012).

On one hand intensive soil tillage reduces soil organic matter through aerobic mineralization, on the other hand low tillage and the maintenance of a permanent soil cover increases soil organic matter. No or low tilled soil conserves the structure of soil for fauna and related macrospores to serve as drainage channels for excess water. Surface mulch cover protects soil from excess temperatures and evaporation losses and can reduce crop water requirements by 30 percent. Conservation and organic agriculture that combine zero or low tillage and permanent soil cover are facilitating adaptation options for soil ability to increase organic carbon level reduce mineral fertilizers use and reduce on farm energy costs (Adaptation to climate..., 2007). Autonomous adaptation is the farmer reaction to precipitation patterns changing crops or uses different harvest and planting or sowing dates. Long term adaptation includes structural changes in land use to increase yield under new conditions, to bring into effect new technologies and land management and water use efficiency related techniques.

Early warning and risk management systems (EWIS) are efficient contributors that can further adaptation to climate change. Important information on databases (DB) are a historical climate data archives, an archive on climate impacts on agriculture, monitoring tools using systematic meteorological observations, climate data analysis, information on the characteristics of system vulnerability and adaptation effectiveness such as resilience, critical thresholds and coping mechanisms. Food and Agriculture Organization of the United Nations (FAO) is a leader in implementation new data format standards of new data types and specific tools (methods and software) and methods such as data interpolation in time and area, and analysis tools at different levels. These activities need to focus on securing agricultural productivity in a sustainable way. Familiar and well-considered are EWIS and Disaster Information Management System (DIMS) that can be used for estimation while contributing to disaster readiness and elimination of potential risks.

Local climate changes. In the Climate Change Mitigation Policy for Latvia among other goals to achieve is increase of efficient and rational use of resources in agriculture and implementation activities such as promotion of environmentally sound agricultural methods that reduce direct greenhouse gas emissions. The main aim of agriculture is sustainable use of agricultural resources by development of environmentally friendly agriculture and promotion of Good agricultural practices (Agriculture, 2012).

Farmers of Latvia climate changes perceive as uneven rainfalls during vegetation period, longer periods of autumn, a very early or late spring, sustained rain or drought and winter thaws. This creates the need for more flexible choice of crop varieties and the application of effective production technologies. The main adaptation measure is to vary inputs of agrochemicals and amounts of fertilizer applications, alter time of application and vary amount of chemical control of pests.

Global society changes. IPCC is the leading international body for the assessment of climate change. IPCC was established by the United Nations Environment Program and the World Meteorological Organization to provide the world with a comprehensive assessment of the current situation of climate change and its potential environmental and socioeconomic impacts (Managing the Risks...., 2012).

In next few decades growth of middle class people in the world is expected from 1 900 million in year 2012 to 4 800 million in year 2030. To feed the worlds whole population in the year 2030, predicted to be 8 500 million, current food production will need to double in order to meet minimum requirements. Huge increase in global food demand projected for the next 20 - 30 years poses immense challenges for the sustainability both of food production and terrestrial and aquatic ecosystems and the services they provide to society. Farmers as main managers of global cultivated lands could change, eventually irreversibly, the surface of the planet in the next decades.

Agriculture today feeds 6 000 million people. Global grain crop production has doubled in the past 40 years mainly from increased yields resulting from greater inputs of fertilizer, water and pesticides, new crop strains, and other technologies of the „Green Revolution". Due to that prior task for agricultural producers is food security and product quality (Tilman et al., 2002).

Considering large area of agricultural lands new technologies are demanded for collecting sensitive data and evaluation of these data.

ICT adoption in rural community. As it is said before the only way to raise productiveness of agriculture is adoption of new ICT technologies in rural community. Adoption of ICT enabled information systems for agricultural development and rural viability is a strategic concern worldwide. Furthermore adoption of ICT in rural community is the only way to avoid irreversible and adverse effects on the Earths nature.

ICT for precision farming. The application of GNSS sensors and machine control to agriculture, with a prescriptive approach that matches maps of the field nutrients and soil condition, has had a valuable impact on increased yields and cost savings for farmers.

An essence of precision agriculture solutions is site specific crop management. That incorporates different aspects, such as monitoring soil, crop, and climate in a parcel and extrapolating the results to complete field. Precision farming provides decision support systems (DSS) with actual data for taking differential actions, for instance, data necessary for variable rate application of fertilizer, lime, and pesticide, or for tillage, or sowing rate in the real time.

WSN for precision farming. As a rule industrial agriculture operates with pretty large fields from tenth till hundreds of square kilometers. It makes cost rise skyrocket for any technology used. Large scale low-cost WSNs obviously are the only way for large field condition monitoring in real time thus they become a part of future farm as the key component for future Internet of Things. This article deals with design and implementation of future Things of Internet.

Materials and methods of research

As follows from the said above development of technologies for large scale networks becomes crucial for sustainability of today's agriculture.

During the current research specifications of hardware, WSN operating system, and supplementary software specifications were assessed and first drafts of them created. In terms of research sensors, technologies, microcontrollers, and available WSN radios part base selected. Together with farmer usefulness of gathered data for particular applications evaluated.

Figure 1 shows organization of the experiment. A mock up of WSN prototype consisted of 6 sensor boards and 1 gateway, namely AgroSeNET.

The equipment was installed in a cranberry parcel for monitoring processes of **radiation frosts**. The nodes were manually localized and positioned using A-GPS and placed on map of the field. The AgroSeNET nodes were equipped with dual sensor for registration both temperature and relative humidity of air, and sensor for registration temperature of cranberry leaves. In addition some nodes were equipped with sensors registering luminosity, air pressure, precipitation, wind strength and direction of wind.

Previous researches show that radio coverage of nodes is significantly reduced when crop is flourishing (Goense et al., 2005). To avoid impact of crop canopy of leaves on communications the radios of nodes were installed at height of 200cm while the sensors were installed at height of 70cm and in the level of cranberry leaves. Distance between nodes was about 200m. A number of sensors for soil humidity measurement were deployed in the field also.

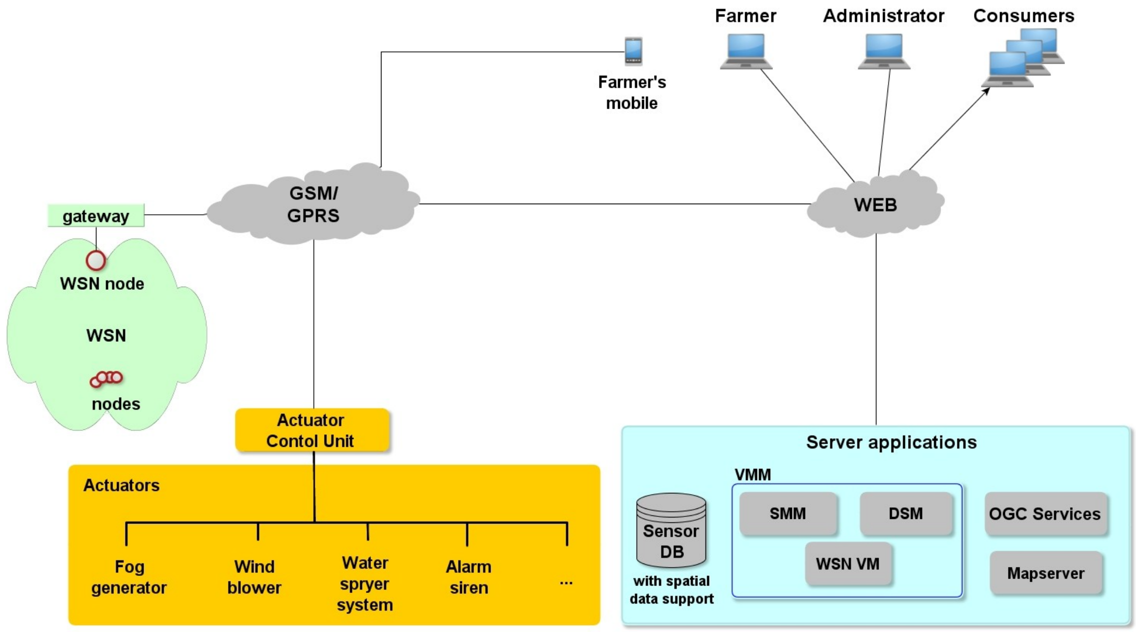

Fig. 1. **Block schematics of the experiment**.

WSNs have emerged as a result of recent advances in low-power digital and analogue circuitry, low-power RF design and sensor technology. Sensor networks are distinct from traditional computing domains. WSNs are composed of motes that are standalone pieces of hardware equipped with a tiny computer power and a radio transmitter. One of the greatest challenges that these types of networks have to face is the energy consumption requirements. Since the network nodes are located in the open and have no accessible energy sources they have to rely on limited size batteries or have they own energy scavenger ability from solar panels or wind turbines. Nevertheless WSN nodes must be built as energy saving as possible. This has led to developments of communication protocols that balance transfer speed with battery consumption like the IEEE 802.15.4, the ZigBee or the 6loWPAN. Other network protocols used are the MyriaNed or the DASH7. The protocols mentioned can provide network with communication ability. However these protocols are not operating systems and they are not enough functionality for use for large scale WSNs.

Sensors and their interfaces. There is a wide range of sensors used for agriculture. Sensors could be used for measuring atmospheric data, soil characteristics, yield qualities, and several plant attributes. Among sensors used for capturing yield qualities we can enumerate several technologies used for measuring agricultural inputs and outputs such as: impact, comb, optical, radiometric, load cell, and torsion/deformation sensors. Besides them we can place activity sensors in the harvester's head, humidity sensors, GPS positioning (DGPS differential GPS or RTK real time kinetics), tilt sensors, quality sensors.

Atmospheric sensors gather temperature, wind speed, wind direction, wind chill, humidity, solar radiation, pollution factors, rainfall, barometric pressure information, etc. Among the soil characteristics clay content, solar irradiation on the soil, soil's temperature, soil's humidity, pH, salinity, nutrients, organic matter, and soil's depth could be measured.

Optical sensors belong to the category of remote sensing techniques. The optical sensor can be mounted into a portable/static terrestrial sensor, a system of unmanned/manned aerial vehicles and finally satellites. The most common technique is hyper spectral imaging which analyses the complete spectrum of light that reflects from the soil or the plants.

By interface sensors are divided into two main groups:

- **analogue sensors** have advantage of simplicity and low price. Disadvantages - measurements are usually obtained from the sensor in raw form. Measured data have to be recalculated for scaling, zero setting, and linearization calculations are usually done by data recorder (data logger). In case of WSN calculations have to be performed by a microcontroller of node. Disadvantage is that at one signal lead only one sensor could be added. Despite the drawbacks the analogue interface is popular and perspective because each ADC input of modern micro-controller is provided with individually settings for the zero shifts and scaling. Linearization function have to be provided by sensor driver software module;

- **digital or intelligent (smart) sensors** have advantage of scaling, zero setting, linearization, even calibration ability. Digital sensor interface with micro-controller unit is commonly used for connection to addressable data bus, i.e., in a single data line may be a number of sensors.

The most popular sensor buses for the environmental monitoring and precision agriculture are SDI-12, I2C, PWM (pulse wide modulation), SDM (sigma delta modulation), MAXIM 1-wire, UART and some others. The output signals of PWM and SDM sensors are easy convertible by low pass filter to analogue DC voltage output.

By mechanical design sensors can be divided into two groups:

- **constructively finished products** which are connected to the sensor node by cable;
- **sensors built in to the node housing**, usually these are specialized chips. Some of them are used for the monitoring of the node (battery voltage, battery charging and e.t.c., others can be applied for environmental monitoring - solar radiation, ambient light, air temperature and humidity, barometric pressure and e.t.c.

Sensor power consumption. The publications of researches of WSN energy consumption often do not pay due attention to their own sensor energy consumption. Sometimes it can exceed energy consumption of wireless network node. Therefore, it is important to keep in mind sensor energy consumption when selecting necessary sensors, optimize sensor placement, and individual measurement frequency, for example soil moisture measurement may be able to take less frequently than the air temperature measurements.

Results and discussion

WSN Visualization, Monitoring and Managing (VMM) application.

In the framework of this research WSN Visualization, VMM application as a component of WSN prototype with future aim (see Figure 1) for precision agriculture was developed.

Development of VMM application is based on principles described by INSPIRE directive and OGC standards. The standardized approach gives possibility for easy adoption into larger systems in the future.

VMM application deals with:

- monitoring of weather conditions within field equipped with WSN,
- initiation of proactive steps to protect crop from unfavorable weather conditions (e.g. automated cranberry field protection against radiation frost).
- management of historical data according to crop growing environment.
- management of metadata of WSN configuration and sensor observations.

To ensure compatibility in the future with any external system VMM application is built using open interfaces based on Open Geospatial Consortium (OGC) standards and data formats described by INSPIRE directive and the following components:

- Metadata and catalogue system (Micka),
- OGC Web Map Service (WMS), Web Feature Service (WFS) and OGC Sensor Observation Service (SOS) compliant server (MapServer),
- Data storage for vector data (PostgresSQL+PostGIS),
- Data storage for raster data (file system),
- Data maintenance and publishing system (Django, Python frameworks based web application).

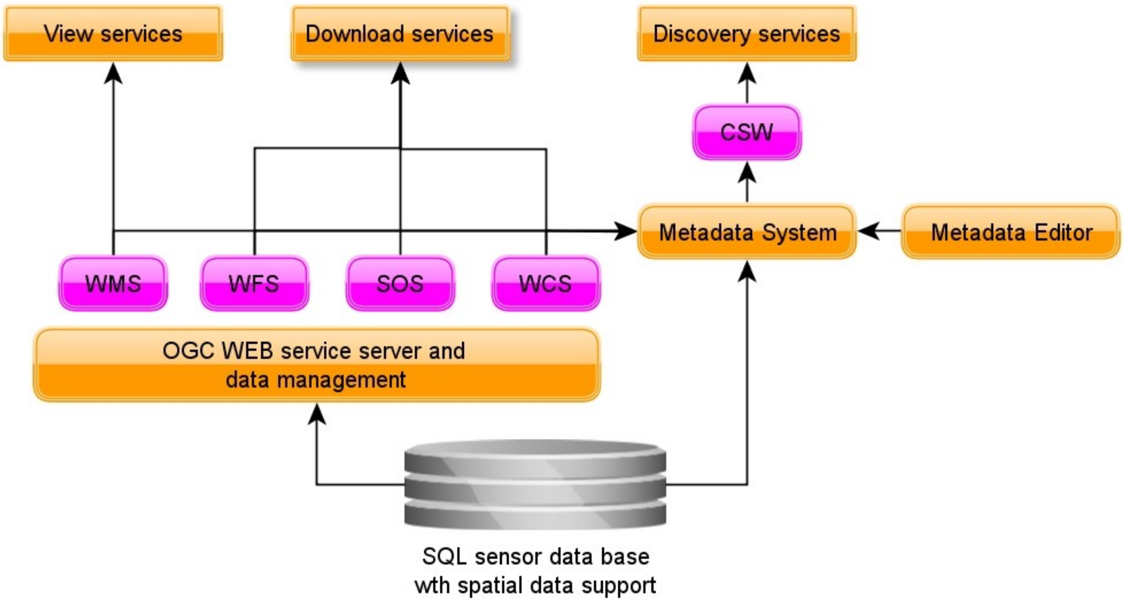

Fig. 2. **Services**.

VMM application is developed using Django, Python, HTML, CSS, AJAX, JavaScript (libraries OpenLayers, GoogleMaps API, GeoExtJS) and it can be accessed by most of modern web browsers.

Postgres SQL is used for sensor data base with open source software plug-in PostGIS supporting spatial geographic objects.

VMM consists of the following modules:

Decision Support Module – (DSM) analyzes observation data from sensor DB by regular polling tables, using mathematical methods (Snyder and Melo-Abreu, 2005) for forecasting dangerous weather conditions and creating event for SMM;

System Managing Module – (SMM) after receiving event from DSM either sends command to Actuator Control Unit (ACU) to start/stop action in **automatic mode** or sends SMS via GSM network to Farmer in **manual mode**.

WSN visualization and monitoring module (WSN VM) allows to view the map of WSN configuration and sensor observation data in different modes depending of Farmer`s settings either in real time or in selected time interval.

VMM allows select **3 levels of access rights**: for administrator (full access), for farmer (view all sensor data and set parameters for SMM and DSM) and for consumer (view all sensor data).

Figure 3 shows curves of both temperature of air at 80cm height and temperature of cranberry leaves during night hours May 13-14 2012. This is excellent example and shows difference of behavior of temperatures. Relative air humidity became as low as 60% without wind and absolutely no clouds. The circumstances reached created conditions typical for radiation frosts.

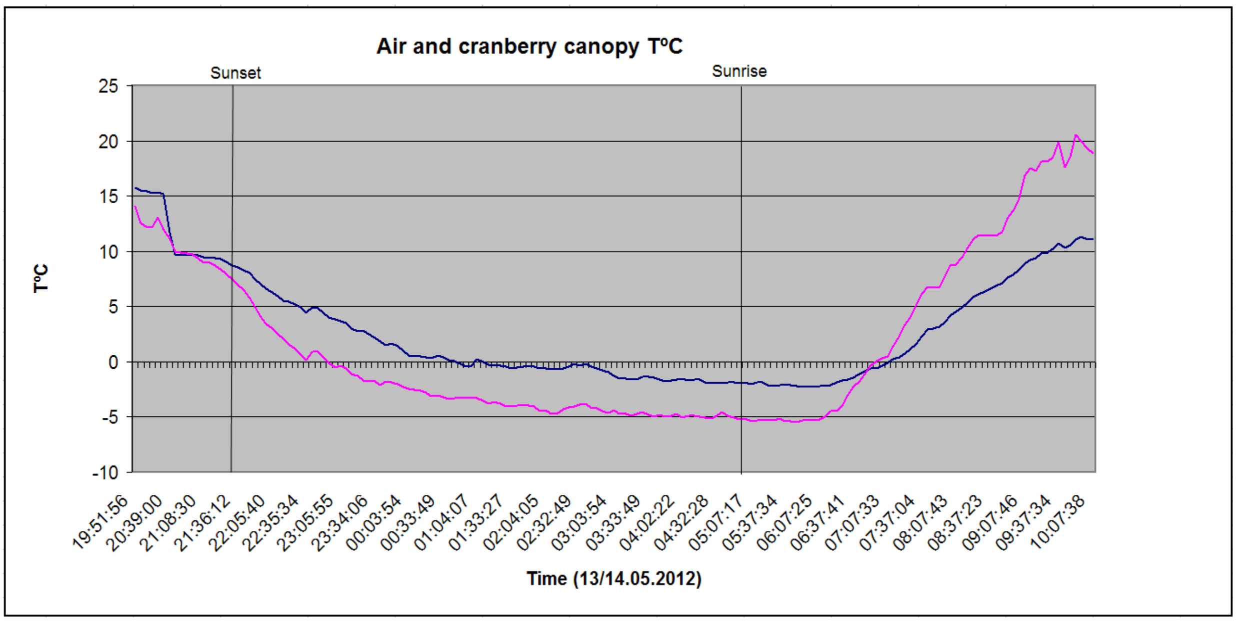

Fig. 3. **Temperature curves**.

During the experiment measurement of temperature, luminosity, air pressure, precipitation, wind strength and direction were collected. The data gathered was necessary input data for using mathematical methods implemented by Decision Support Module (DSM).

Mathematical methods implemented in DSM are based on models of the original paper by Allen for the frost temperature trend model implemented in FFST.xls and FTrend.xls (Snyder and Melo-Abreu, 2005). Two hours after sunset is starting time (t_o) of the model. t_o corresponds to the moment when the net radiation reaches minimum. Assuming there is little or no cloud cover or fog during the night, the net radiation changes little from time t_o until sunrise the next morning. If there are clouds or fog, the model will forecast temperature lower than observed. If a cold front passes or if there is cold air drainage, the forecasted temperature may be too high. For use in the application program for the model, data are selected only from radiation frost nights. Measurements from nights with wind speed values greater than 2.0 ms^{-1} (5 mph) and nights with cloud cover or fog was excluded.

FTrend.xls implemented mathematical model is used to determine temperature trends during a frost night for air, wet bulb and dew point temperatures to forecast how the temperature will change during a radiation frost night from two hours after sunset till sunrise. Sunset and sunrise were determined from the input latitude, longitude and date. The model uses calculations to forecast the air temperature from the start time (t_o) until reaching the forecasted minimum temperature (T_p) at sunrise (at time t_p) the next morning. Air temperature is calculated corresponding to the air and dew-point temperature. Appropriate actuators on the crop field were used when the wet bulb temperature approached to the critical damage temperature.

As mentioned 8], there is another forecast method that was developed by Krasovitski, Kimmel, and Amir (Krasovitski et al., 1996). This method gives more precise forecasting; however implementation of the method is much more complicated. For starting point of researches we decided to apply FAO recommended and above described method. If future researches will show forecasted results will much differ from real ones then it will be useful to try the second method.

As it was discovered during the experiment early forecast is crucial. Because it is too late use any protection, for instance, artificial wind or fog when radiation frost already taking place; the only way is gathering data and calculating probability of radiation frost as early as possible and start protection actions at least 1 – 2 hours before leaves reach dangerous temperature levels.

The experiment gave answer to many questions according to technical realization of WSNs hardware and software. It brought us to idea construct our own based on new concepts WSN hardware and additional alignment of software specifications.

Basic requirements for WSN Operating system (FarmOS).

OS have to be an operating system for large scale WSN. To create that kind of networks there are specific requirements to make network stable. One of the main issues is to guarantee stable communication in long distances with resolution of collisions and self managing topology while meeting legal regulations for radio communications. To support robustness and flexibility of such large scale WSN systems FarmOS have to support:

- collision resolution support for large number of nodes;
- low energy consumption;
- WSN radio communication in three different topologies (star, multihop, mash)

- addressing, MAC protocols, multi-hop routing;
- multitasking;
- unlimited number of software timers;
- compile time configuration for inclusion and exclusion of specific options;
- interactive shell for basic controls and data access;
- integrated development environment;
- analog and digital sensors (including I^2C, SPI, SDI-12 protocols);
- integrated scripting language, etc.

To make system flexible and easy manageable architecture of FarmOS should be structured in three main layers:

- HIL - Hardware Interface layer - hardware independent services that should support any hardware;
- HAL - Hardware abstraction layer - provides services specific to hardware platforms - sets of modules and chips;
- HPL - Hardware presentation layer defines the services by the lowest level of hardware.

On top of the structure there are device drivers and device manager defined allowing unified and selective access to the resources by all applications.

Interface between the user applications and the FarmOS are the system calls.

It would be convenient if FarmOS applications could use plain C and UNIX like system concepts, for instance, sockets for communication. The FarmOS would be easy assessable for most people who have some system programming experience even for those who are new in embedded systems.

As a result an application can be developed without the specification of the hardware. In fact, one of the platforms provided is PC that allows for immediate application debugging and simulation at a high level (Qing Cao et al., 2008).

FarmOS have to have built in scripting language system suitable for common WSN applications in readable and intuitive way. For instance, only a few code lines are required to specify the basic "read sensors" or „send readings to radio" applications.

The graphical user interface allows writing applications in FarmOS even for people with little or no programming experience.

The features above would make FarmOS robust and convenient for agricultural application design, implementation, and maintenance. The main goal is possibility to use large scale WSN systems running on FarmOS in harsh real field environment with little or no ITC personnel support and interaction.

To build large scale WSNs for use in agriculture some specific requirements have been discovered.

Basic requirements for large scale WSN long range node hardware and its solution (Krivanek et al., 2012).

- size of transmitted data (sensor type and the measured value) is approximately 6B (byte) for one variable and one measurement;
- data is read by the Access point node in periodic intervals that can be configured. The shortest possible interval is 60 seconds;
- network nodes must keep working without recharge of batteries at least 6 months (roughly – one agricultural season) performing data collection at least once every 2 hours;
- nodes could be equipped with energy harvesting elements for example with solar cell;
- management and operation of network elements (nodes) must be easy and robust;
- communication range between nodes must be about 250 m to 500 m in the field of forest;
- network nodes should be able to perform simple computational operations; such as zero offset, sensor transfer function, scaling and linearization, dew point calculation from air temperature and humidity measurements e.t.c.;
- easy integration of measured data;
- ability of WSN base station (WSN gateway) to connect to existing public wireless networks;
- operating frequency of 868 MHz or lower in SRD(ISM) bands;
- power consumption of nodes and its sensors must be as low as possible, the capability of recharging its battery for scavenging energy from the environment, and very limited processing capabilities;
- each node and its sensors should conform with enclosures protection ratio code at least to IP65.
- each node should has an unique ID number, written in hardware.

Sensor node should be considered as one entity with its sensors. Without sensors node loses sense of existence. It means that requirements to sensor node mean requirements to sensors connected too. What kind of sensors is needed and what requirements are applied it is defined by application. This research deals with long range sensor network for precision agriculture especially for protection of American cranberry from radiation frosts.

Combining know how obtained from field experiment described above, research in field of WSN, engineering knowledge a state of the art functional schematics of a new (namely - LUMII WSN) node was created (Figure 4). This schema and mechanical engineering of node solves row of problems of AgroSeNET hardware discovered during research. Schema contains some elements that can be regarded as inventions.

To describe hardware functionality of the LUMII WSN node description should be started with logical components.

Energy harvesting and power management. Different ambient energy sources can produce electrical power. Implementation of photovoltaic energy harvesting today could be done in relatively low costs. Because of its high energy output, photovoltaic cells could be used not only to power up wireless sensor nodes, but also recharge the batteries. Main task of energy harvesting circuit is to gather maximum energy in different solar cell lighting and battery load conditions. For energy harvesting and battery charging of the node solar panel consisting of two solar cells and energy harvesting integrated circuit (IC) LTC3105 from Linear Technologies are chosen. The solution offered is dealing with two tasks; the first one is recharge of the battery, the second is a measurement of solar radiation level. Solar cells are switched in short circuit mode for solar radiation measurement by switching on analog MOSFET switch SW1 (Figure 4). Solar cell pyranometer – the problem is that it does not measure the whole spectrum of the sun radiation. Therefore it is advisable to use a professional pyranometer to calibrate a photovoltaic instrument.

Two SANYO Eneloop Rechargeable lite long life AAA batteries (up to 2000 cycles) are chosen (Bourgoine, 2011).

Micro-controller. Microcontroller must have enough RAM, to execute the program, and enough flash memory, to store program and data. Microcontroller must have low energy consumption. To connect to all necessary digital sensors and radio transceiver microcontroller must have enough ADC inputs to interface with analog sensors and digital interfaces such as I2C, UART, SDI-12, SPI, 1-wire . The Texas Instruments microcontroller MSP430F2272 with 1 KB RAM and 32 KB flash memory is chosen for LUMII WSN node.

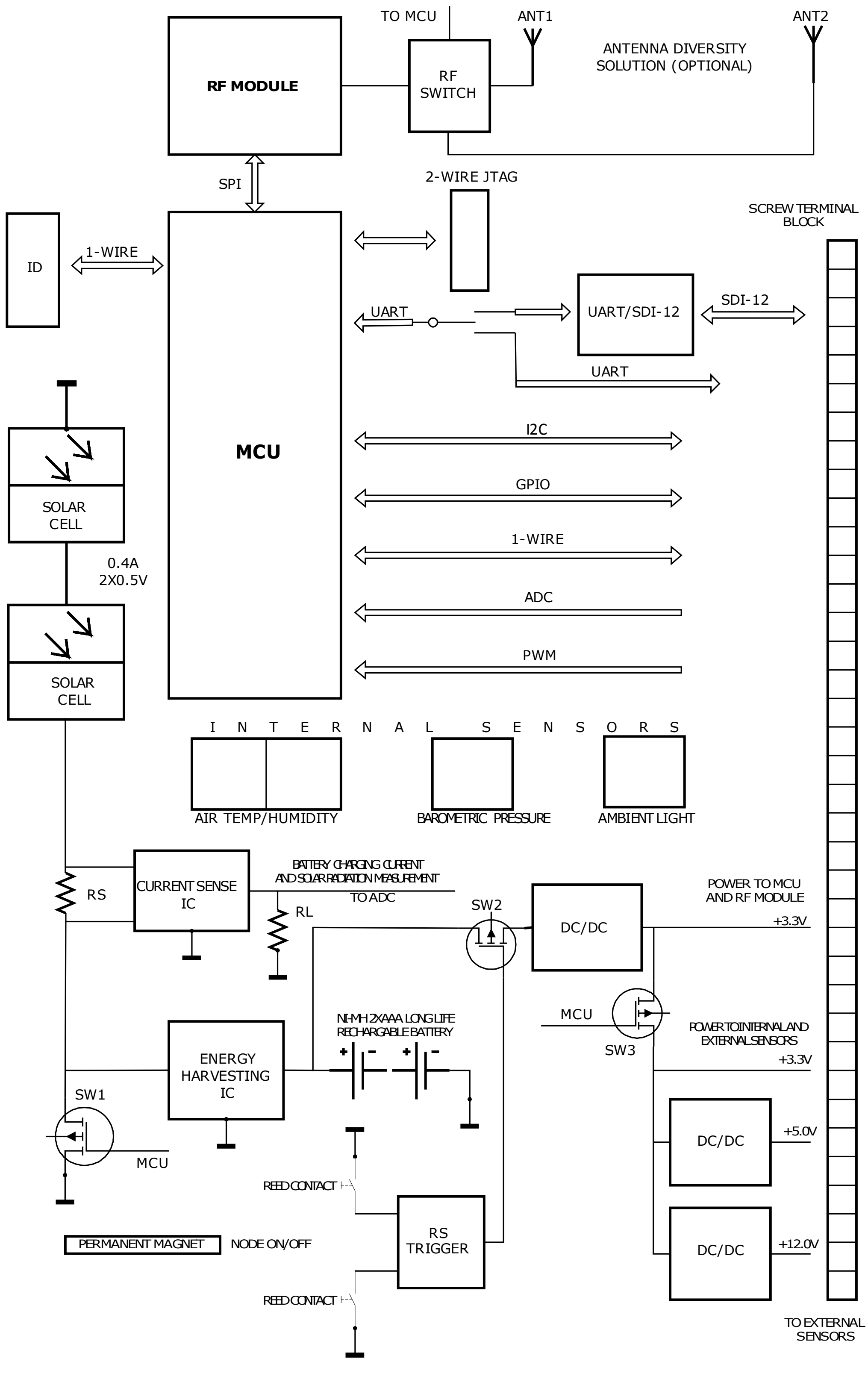

Fig. 4. **Schematics of LUMII WSN node**.

RF module (transceiver). Radio transceiver is the key element of WSN node. It's a main module determining quality of the network. To complete tasks determined by application it is crucial to chose appropriate transceiver chip, frequency band, channel bandwidth, data rate, and modulation technology. As it is mentioned above to perform a measurement of one phenomenon 6 B (bytes) of data are necessary; minimal time interval between measurements is considered 60s for meteorological measurements for agriculture use.

According to European table of frequency allocations and applications frequency range of 863-870 MHz is planned for use of Short Range Devices (SRD). According to ERC recommendation 70-03 relating to the use of SRD devices the maximum transmitting power must be not grater than 25 mW (+14dBm), maximum duty cycle for transmitter is 1%. From these specifications it follows if the time interval between measurements is 60s the transmitter should not be in active mode more than 600ms. Assume, the sensor node measures 8 phenomena – air temperature, humidity, barometric pressure, solar radiation, soil moisture, soil temperature, battery voltage, battery charging current. The common amount of data sent for one measurement cycle to access point, will be 8X6=48B (bytes) or 48X8=384b (bit). To fit in 600ms necessary data transfer rate will be 384bps/0.6s=640bps. Higher data rate requires larger radio channel bandwidth for receiver. According to the Nyquist theorem power of thermal noise applied to the receiver input is proportional to the bandwidth of the channel. The way to increase data transfer rate is by reducing link budget. By increasing data transfer rate data transmitting time and duty cycle decreases hence energy consumption of node goes down. In forested areas multi path fading takes place. Implementing of antenna diversity for forested areas is good solution.

Features of some Texas Instruments RF transceivers, appropriate for low bandwidth, low data rate, long range radio transmission at 868MHz frequency band are shown in Table 1.

Table 1

	CC1101	**CC1120**	**CC1125**
Min channel bandwidth, kHz	58	8	2.8
Min channel spacing, kHz	100	12.5	4
Receiver sensitivity at 1200 bps, 1% packet error rate	-112dBm	-123dBm	-123dBm
Receiver sensitivity at 300 bps, 1% packet error rate	N.A.	N.A.	-129dBm
Adjacent channel rejection	37 dB	64 dB	67 dB
Image channel rejection	31 dB	66 dB	66 dB
Current consumption in SNIFF mode	N.A.	3.7 mA	2.0 mA
Average current consumption in RX sniff mode, checking for data packet every 1 second, using Wake-on-radio	N.A.	15mkA	15mkA
Max transmitter output power	+12dBm	+16dBm	+16dBm
Sniff mode	No	Yes	Yes
Wake-on-Radio functionality (WOR)	WOR	Enhanced WOR	Enhanced WOR
Antenna diversity support	No	Yes	Yes
Link budget	124 dB	139 dB	145 dB

For WSN prototype consisting of 50 nodes Anaren 868MHz RF module based on TI CC1101 transceiver IC has been chosen. Several WSN nodes will be built using 868MHz RF module based on either TI CC1125 or CC1120 transceiver IC will be built for research purposes. Cranberry field protection against radiation frosts requires specific internal and external sensors for new LUMII node.

Internal sensors:

- air temperature/humidity measurement with dew point calculation possibility - the Sensirion IC SHT21P with PWM interface;
- barometric pressure – the Freescale Semiconductor IC MPXH6115A6 with analogue voltage interface;
- ambient light – the ROHM IC BH1603FVC with analogue current interface;

External sensors:

- soil moisture – the VEGETRONIX VH400 with analogue voltage interface;
- soil temperature – VEGETRONICS THERM200 with analogue voltage interface;
- wind speed - INSPEED VORTEX WIND SENSOR with reed contact output interface (frequency of reed contact switching is measured);
- wind direction - INSPEED E-VANE Hall effect sensor with analogue voltage interface.

Engineering development of the node. The node must be fully protected against dust and heavy rain, i.e., the housing must meet at least IP67 class. The housing of node has to be fitted with transparent cover, to locate the light sensor and solar panel inside the housing. Gas-permeable membrane filter ventilation system must be installed on the housing to provide the same atmospheric pressure, air temperature and humidity of the outside. It gives a chance to fit environmental monitoring sensors inside the housing. This would allow the part of sensors to place within the housing, protecting them from exposure of the environment and reduce the cost of nodes. The junction box is to be used for connecting the external sensors without opening the housing of the node. The cable between junction box and housing of the node has to be pressurized with cable glands. The node is to be equipped with non-contact switch, for example, permanent magnet steered reed, which can be turned on and off. The mechanical design of node has to provide user-friendly and simple fixation on the field.

Conclusion

Deployment of sensor networks still is a problem and subject of wide range researches and developments. Prototype of WSN built in framework of current research shows that small networks are more or less functional while large scale WSNs with long range nodes are issue. Despite of problems our WSN prototypes gave possibility to gather valuable data for field weather monitoring.

The gathered data enabled us to evaluate both conformity with reality of couple of theoretical mathematical models of radiation frost forecasting with reality and features and advantages of AgroSeNET technology in conjunction with just developed WSN operating systems FarmOS beta versions. We got a valuable experience and lessons according to insights of WSNs. Additionally we discovered row of problems using WSNs in great distances more than 300m and in large networks e.g more than 50 nodes.

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