Sensor microassemblies with radio frequency identification for temperature measurement

K A Muraviev, P V Grigoriev, V V Leonidov, A I Krivoshein, T A Tsyvinskay, V O Semenyakina and E R Zakharov

Bauman Moscow State Technical University, 5, 2-ya Baumanskaya, Moscow, 105005, Russia

E-mail: kostiktakaya@gmail.com

Abstract. The present article studies the approach to building the distributed wireless sensor networks. It shows that, for RFID-based wireless sensor networks, the first thing to determine is the field it is intended to be used for, the far or the near one. The operating frequency value determines the size of the antenna, and the correlation is inverse. The operational contradiction analysis shows, that to increase the operating range of the tags, it makes sense to select the systems with an active power supply. But from the energy efficiency perspective, the passive tags are better to be used, and for increasing the range of data transmission, coordinators that collect and transmit the data to the central unit are preferable. Wireless sensor networks technology is the only wireless technology that can be used for solving some surveillance and control issues, where the time of processing of the sensor readings is critical. United into a wireless network with the suggested method, the sensors make up a spatially distributed self-organized system of collection, processing and transmission of information. A special attention is paid to the structural solution for temperature control in the wireless sensor networks elements. In the conclusion, recommendations on using radio frequency identification technology-based sensor systems are provided.

1. Introduction

Development of wireless information transmission modules becomes more and more important while designing the internet of things [1]. At the present time, various wireless communication protocols are widely used [2]. In the present paper, we will study the specificity of the construction of RFID-based wireless sensor networks (WSN). The first step in the RFID sensor design is to determine the field it will be used in, the far or the near field, as it is the operating frequency that determines the scope of use [3, 4]. The operating frequency value determines the size of the antenna, and the correlation is inverse. Figure 1 presents the diagram of the operational contradiction [5] which occurs in the process of design of the topology of the far-field RFID-system tag.

Operation contradiction analysis may be presented as a chain of cause-and-effect relations. To increase the operating range of the tags, it makes sense to select the systems with an active power supply. But from the energy efficiency perspective, the passive tags are better to be used, and for increasing the range of data transmission, coordinators that collect and transmit the data to the central unit are preferable [6-8].

Therefore, the object of the research is the tags with high (for the near field) and ultrahigh (for the far field) ranges of operating frequencies.
It may be stated that, compared to other automated identification methods, RFID technology has a number of advantages [3, 4, 9]:

- contactless operation: RFID tag data can be read without any physical contact between the tag and the reader;
- overwriting of data: RW tags make it possible to update the data stored by the tag a number of times, in accordance with the changing system operation requirements of the customer;
- working outside the line-of-sight zone: generally, reading a RFID tag does not require it to be within the line-of-sight of the reader;
- diversity of reading ranges: RFID tag reading range may vary from several centimetres to several tens of meters, depending on the RFID-system frequency and the reader transmission power;
- multiple data storage opportunities: a RFID tag may store the volume of information from one bit (the so-called EAS-tags) to the almost unlimited amounts (for widespread applications there are affordable tags with the memory ranging to 4 Kilobyte);
- multiple tag reading support: an RFID reader may automatically read several tags within its range during a short period of time;
- durability: RFID tags are resistant to the adverse effects of the environment;
- intellectual tasks: besides the storage and transmission of data, an RFID tag may perform other functions (e.g. a temperature sensor may be embedded into an active tag).

However, RFID technology has its limitations. It should be noted that some of the current limitations may be resolved as the technology improves.

Among the major limitations of the RFID technology, there are [3, 4, 9]:

- low operation characteristics in the presence of radio pacifying and radio absorbing objects;
- effect of the adverse factors of the environment;
limited number of readable tags;
- effect of the noise produced by various equipment units.

WSN technology is the only wireless technology that can be used for solving some surveillance and control issues, where the time of processing of the sensor readings is critical. United into a wireless network, sensors make up a spatially distributed self-organized system of collection, processing and transmission of information.

2. Integrated sensor microassembly architecture with RFID identification

The "classic" sensor network architecture is based on a standard node, which includes: central node, control module, power supply, various sensors. Using a second transmitter complying with ISO 24730-5 in a typical sensor network node makes it possible to use the sensor network not only for the surveillance over the parameters of environments and objects, but also for location determination and movement tracking of the RF-tagged objects. A sensor network made up of such nodes constitutes the wireless RTLS infrastructure. The information read from the sensors is processed and stored in the control module. After that, it is transmitted into the central node to be transmitted to the next element of the network.

Using RFID technology in the sensor networks may minimize the amount of consumed electric power by using passive RFID tags. The sensors are not constantly connected to the power supply. In other versions of the sensor networks, the units are integrated with switch boards for further transmission of data; if the switch boards are replaced with the same nodes, it will minimize the number of elements in the system, making it more reliable.

Let us consider the specificity of integral implementation of a RFID temperature sensor; the structural solution is demonstrated in figure 2. It is designed for indoor temperature control; maximum reading range is 8 m within the measurement range from -60 to 120°C with the measurement precision: \(\pm 0.1°C\).

![Figure 2. Temperature sensor: a) Structural implementation: 1 - post, 2 - double threaded post, 3 - printed circuit board with RFID antenna, 4 - cover, 5 - baseplate, 6 - battery compartment, 7 - sensitive element]

On the printed circuit board surface, an electric circuit is installed with the SMC assembly method for processing the signal coming from the sensitive element, installed with adhesive bonding and connected to the contacts of the board with the ultrasonic aluminium wire bonding method. The signal processing system consists of: MLX90308 transistor, STM32F103C8T6 microprocessor, IMPINJ MONZA X-8K transmitter. The power element, a CR2032 button cell Lithium battery, is installed in the battery compartment. Post (2) is fixed on the base plate (5) with a screw. On the post, the printed
circuit board is installed, pressed with the bushing (1) to the bushing (2) on the threaded joint. The cover (4) is connected to the bushing (1) with a screw. The cover and the base plate are made of engineering plastic of TECASINT grade, polyimide; PI is the most heat resistant of all the thermoplastics known in the world today. The sensitive element is a monocrystalline silicon crystal with an integrated circuit board on the planar side of 4x4 mm and 450 µm thick (see par. 2.3).

SMC-mounted sensor models with the operating range from -60 to +80°C and submersible sensors in metal and plastic cases for aggressive environments with the range from -60 to +120°C have been developed. 3D model of the temperature sensor is presented in figure 3.

The entire structure is screwed into a special opening, where the temperature is measured by the sensor 2, using the threaded foundation 4, installed in the sensor tube 3 at a certain distance.

Sensitive element 2 is screwed into tube 3 at the required distance; then the end of the tube is sealed with cover 1. Tube 3 is sealed with laser welding to the threaded foundation of case 4. Sensor 2 is connected with some wires to board 9 through the openings inside the threaded foundation and the base plate of the board case 5 to ensure the transmission of data to the microchip.

To threaded foundation 4, the board in its case is screwed using double-sided posts 6. The printed circuit board is enclosed in a case consisting of base plate 5 and cover 12. It is installed inside the case with posts 6 and 11. The elements are soldered onto printed circuit board 9 using SMC methods. At the lower side of the printed circuit board there is a battery installed in the battery compartment. Case cover 12 is fixed with countersunk headed screws 13. All posts and screws are of M3 size.

![Figure 3. 3D model of the temperature sensor: 1 - sensor tube cover, 2 - temperature sensor (MEMS), 3 - temperature sensor tube, 4 - threaded foundation - device fixation element, 5 - printed circuit board case base plate, 6 - lower posts, 7 - battery, 8 - battery compartment, 9 - board, 10 - board elements, 11 - upper posts, 12 - case cover, 13 - cover fixing screws.](image)

Integration of the RFID module with the sensor information processing board ensures the microminiaturization of the unit size and reduces the cost; however, such a sensor must have a radio-transparent case. Further microminiaturizations shall foresee the possibility of integral implementation of the signal processing module together with the measurement module using the 3D MID integration technology.

The suggested transmitting-receiving nodes implementation concept is based on the manage-agent architecture. The receiver (also being the PAN-coordinator) presents the information measured by the sensor to the user. Moreover, PAN-coordinator may be used for adjustment of the network and data transmission route development. The transmitter digitalizes the information from the sensor, which is received in the analogous form with a small amplitude, for further processing by a microcontroller.
The mentioned devices ensure high precision of information received from the sensor due to the use of the low-noise signal transformation circuit and voltage stabilizer. The result is the functionally complete structure of a transmitter and a receiver required for the construction of the simple peer-to-peer sensor network. The transmitting module foresees a "sleeping mode" for the microcontroller, i.e. the energy-saving mode, which is one of the advantages of the technology.

The presented solution opens new perspectives for robotics [10], industrial control and predictive maintenance systems [11], "smart home" systems and other smart objects [12-14].

3. Conclusion
The suggested solution on the implementation of RFID technology-based sensor networks determines new promising solution for the problem of integration of the silicon structures and RFID units in the "last mile" area. The suggested approaches to the sensor multiassembly design with radiofrequency identification elements are intended to ensure intellectual distributed processing of data.

Acknowledgements
Some results of the project were obtained with the financial support of the Ministry of science and higher education for the project “Fundamental research of methods of digital transformation of the component base of micro-and nanosystems”.

References
[1] Yudin A V, Salmina M A, Vlasov A I, Shakhnov V A and Usov K A 2017 Design Methods of Teaching the Development of Internet of Things Components with Considering Predictive Maintenance on the Basis of Mechatronic Devices International Journal of Applied Engineering Research 12(20) 9390-6
[2] Dargie W and Poellabauer C 2010 Fundamentals of wireless sensor networks: theory and practice (Chennai: John Wiley & Sons Ltd.) 311
[3] Nikitin P V and Rao K V S 2007 Performance of RFID Tags with Multiple RF Ports IEEE Antennas and Propagation Society, AP-S International Symposium (Digest) art 4396783 5459-62
[4] Lam S, Nikitin P V and Rao K V S 2010 UHF RFID Tag for Metal Containers Ports Proc. Asia Pacific Microwave Conf. (Yokohama, Japan/IEEE) 179-82
[5] Vlasov A I and Gonoshilov D S 2019 Simulation of manufacturing systems using BPMN visual tools Journal of Physics: Conference Series 1353 012043
[6] Yuldashev M N, Vlasov A I and Novikov A N 2018 Energy-efficient algorithm for classification of states of wireless sensor network using machine learning methods Journal of Physics: Conference Series 1015 032153
[7] Yuldashev M N and Vlasov A I 2019 Mathematical model of the general problem of state classification in wireless sensor networks IOP Conf. Series: Materials Science and Engineering 498 012002
[8] Yuldashev M N and Vlasov A I 2019 Performance analysis of algorithms for energy-efficient data transfer in wireless sensor networks Proc. Int. Conf. on Industrial Engineering, Applications and Manufacturing, ICIEAM (Sochi; Russian Federation/IEEE) 8743087
[9] Uzenkov D A, Muraviev K A, Vlasov A I and Prudius A A 2019 Load Balancing in Big Data Processing Systems International Review of Automatic Control 12(1) 42-7
[10] Yudin A, Kolesnikov M, Vlasov A and Salmina M 2017 Project oriented approach in educational robotics: From robotic competition to practical appliance Advances in Intelligent Systems and Computing 457 83-94
[11] Echeistov V V, Krivoshein A I, Shakhnov V A, Vlasov A I, Filin S S and Migalin V S 2018 An information system of predictive maintenance analytical support of industrial equipment Journal of Applied Engineering Science 16(4) 515-22
[12] Grigoriev P V, Krivoshein V A, Shakhnov A I, Vlasov A I, Filin S S and Migalin V S 2018 Smart management of technologies: Predictive maintenance of industrial equipment using wireless sensor networks *Entrepreneurship and Sustainability Issues* **6**(2) 489-502

[13] Zhalnin V P, Zakharova A S, Uzenkov D A, Krivoshein A I, Vlasov A I and Filin S S 2019 Configuration-making algorithm for the smart machine controller based on the internet of things concept *International Review of Electrical Engineering* **14**(5) 375-84

[14] Vlasov A I, Shakhnov V A, Filin S S and Krivoshein A I 2019 Sustainable energy systems in the digital economy: Concept of smart machines *Entrepreneurship and Sustainability Issues* **6**(4) 1975-86