Electrical, Control and Communication Engineering
ISSN 2255-9159 (online)
ISSN 2255-9140 (print)
2022, vol. 18, no. 1, pp. 37–42
https://doi.org/10.2478/ecce-2022-0005
https://content.sciendo.com

On the Development of Long-Range Water Quality Monitoring System for Outdoor Aquaculture Objects

Dmitrijs Pikulins* (*Senior Researcher, Riga Technical University, Riga, Latvia*),
Roberts Gotlaufs (*Research Assistant, Riga Technical University, Riga, Latvia*),
Tatjana Solovjova (*Researcher, Riga Technical University, Riga, Latvia*),
Arturs Aboltins (*Senior Researcher, Riga Technical University, Riga, Latvia*),
Juris Grizāns (*Researcher, Riga Technical University, Riga, Latvia*),
Sandis Migla (*Research Assistant, Riga Technical University, Riga, Latvia*)

***Abstract* – The paper is dedicated to the development of hardware and software components for the autonomous water quality monitoring system (WQMS) for fishing farms. The system can measure main water quality parameters, storing and processing data on the remote server. The LoRaWAN technological solutions and infrastructure are utilized, providing the optimal tradeoff between data transmission range and adaptive power consumption. The main implementation and exploitation issues are described, and the proposed solutions are provided.**

***Keywords* – Environmental monitoring, LoRaWAN networks, radio communication, wireless sensor networks.**

I. Introduction

The rapid increase in the number of people on the Earth (around 10 billion in 2050) places additional demands on feed-supply systems, leading to the search for various ways to increase production productivity and reduce environmental impact. In the context of sustainable development, there is a need to review production methods, considering ecological and social aspects, through the transformation and optimization of practices.

The development of aquaculture in recent decades has outpaced that of any other livestock sector. According to the World Bank and the World Resources Institute forecasts, aquaculture production volume will have to reach 93.6 million tons in 2030 and around 140 million tons in 2050. As a result, the industry will have to double its output over the next 30 years, despite limited land and water resources [1]. In general, there is a need to implement sustainable intensification of aquaculture by increasing the productivity of aquaculture facilities.

The increase in aquaculture products is due to the rise in the area used for fish farming and the introduction of intensive farming technologies, which require more active use of feed, fertilizer, and other chemicals to achieve high productivity. These active uses of resources, in turn, can lead to an increase in environmental pollutants, disrupt the biochemical balance and even jeopardize the safe existence of ecosystems while preserving biodiversity. As a result, the aquaculture industry, which is only associated with environmentally friendly processes in traditional growing, is becoming one of the potentially significant polluters of water resources, demanding more attention from monitoring organisations.

The rapidly growing IoT technological solutions and the deployment of wireless sensor networks open new avenues to remote monitoring and control issues [2]–[3]. Some of the recent papers have underlined different aspects of the implementation of IoT WQMS [3]–[5]. Most of them use inefficient data transfer protocols providing high energy consumption and spectrum exploitation, requiring frequent system maintenance and being non-scalable by their nature [6], [7].

Many currently proposed solutions have only been tested in the laboratory environment and do not provide useful information on actual design and exploitation issues in natural ponds [8]–[10].

The current research is devoted to implementing and testing the remote water quality monitoring system for open-air ponds. The distinguishing feature of the proposed system is the development of mechanical solutions for the compact and convenient autonomous data boy. The software design, in contrast to existing solutions, incorporates in a unified manner the real-time data on water quality parameters and the actual activities in the ponds, as well as provides the possibility to automatically turn on/off different types of equipment in the ponds (such as feeders or aerators). This allows the finishing pond administration to get up-to-date data on the water quality and evaluate the effects of improper management activities on the farm. The proposed system also opens a broad perspective in data collection for further analysis and development of the guidelines for the most efficient pond-management strategy.

The rest of the paper is organised as follows. Section II discusses the development of electronic and mechanical components of the sensor nodes. Section III presents the

* Corresponding author.
E-mail: dmitrijs.pikulins@rtu.lv

developed architecture of the software components. In Section IV, the experimental results are provided, and some commonly mentioned practical issues are discussed. Finally, conclusions are drawn in Section V.

II. Development of Sensor Nodes

The WQMS includes two hardware components: electronics and sensors, incorporating specially developed data transmission protocol and mechanical parts.

A. Electronics and Sensors

The main electronic system components are end nodes and gateways. Commercial off-the-shelf LoRa gateways (Kerlink Wirnet Station) were used. Custom hardware and firmware were developed for the end nodes.

The end nodes incorporate the microcontroller (MCU), water quality probes, probe analogue value converters, LoRa modem, GPS receiver and power supply. For easy installation, the node is battery-powered. The node was developed with low power consumption to minimize the need for regular maintenance. The node consists of the main PCBA and five daughter boards with analogue to digital converters for corresponding sensors. The batteries are housed in a separate enclosure for easier replacement.

The selected microcontroller is an STM32L4 series chip with Arm Cortex-M4 CPU. The LoRa modem is RN2483 from Microchip, and the GPS receiver is TESEO LIV3F from ST Microelectronics. Five types of water quality probes (Dissolved Oxygen, Electric Conductivity, pH, Temperature and ORP) and analogue to digital probe signal converters from Atlas Scientific are used. To minimize power consumption, the LoRa modem, GPS receiver and each Atlas Scientific digital converter are put behind load switches to cut power during sleep.

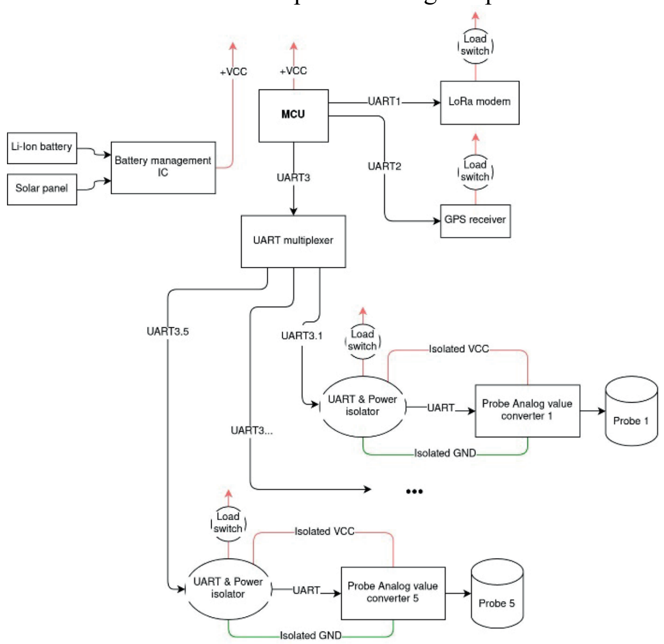

Fig. 1. The block diagram of the wireless sensor nodes.

The node is powered by two 18650-type Li-Ion batteries and a small single-cell solar panel through a BQ25570 power converter from Texas Instruments. The converter integrates maximum power point tracking (MPPT) boost converter for solar power harvesting and a high-efficiency buck converter for the node main power supply rail. Also, it has battery charging and protection components, all in a single chip.

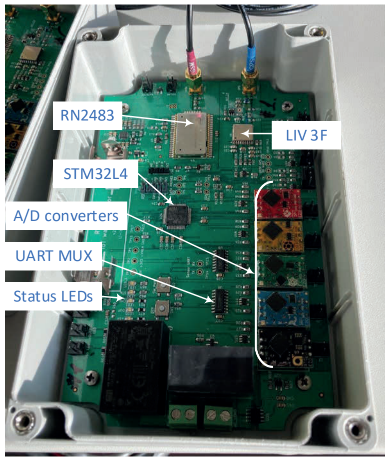

Fig. 2. The PCB of the experimental prototype.

A similar node was constructed for controlling mains-powered aerator devices. It is powered from mains voltage through an integrated isolated step-down converter with a backup battery. The aerator is controlled by a relay and a magnetically coupled integrated current sensor ACS752x from Allegro Microsystems. This aerator node does not have water quality probes or solar panels.

The firmware was developed in C++ using STM32 HAL and Embedded Template Library in a super loop style with a custom event timing engine. All available microcontroller sleep states were used for maximum power savings. It is worth noting that significant effort was required to work around bugs in RN2483 module firmware.

B. Mechanical Parts

Wireless nodes incorporating sensors should be situated in different parts of the ponds, according to the requirements of the actual user. Thus, the special mechanical construction – data buoy – was designed to provide reliable and convenient placement and service of the nodes.

The main components of the data buoy are depicted in Fig. 3. The electronics box is put into the construction made of foam rubber and plywood, covered with polyurethane. The upper watertight cover protects the electronics from water and provides simple maintenance of the systems. All water quality sensors, being the most vulnerable components of the system, are placed in the special protective caging.

The designed solution allows for simple transportation, exploitation and maintenance of the system, which has been proved during the long-term tests.

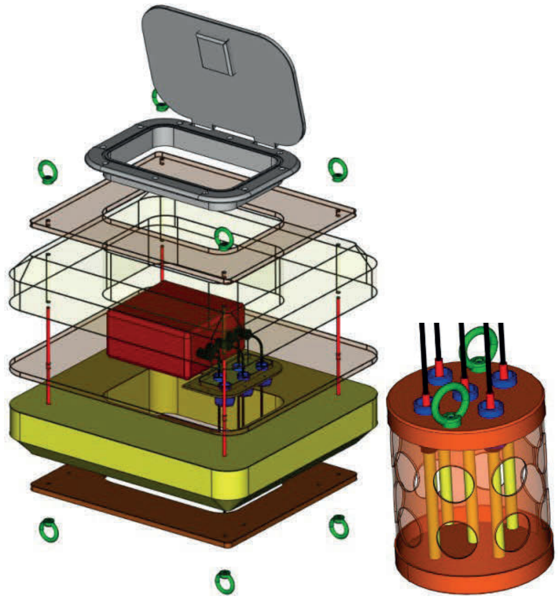

Fig. 3. Mechanical components: buoy construction and sensor protection cage.

C. Communication Protocol

The system works on The Things Network LoRaWAN network with the EU868 frequency plan. The spreading factor is negotiated automatically using Adaptive Data Rate. The LoRaWAN stack is integrated into the RN2483 LoRa modem, available over a UART connection to the main MCU. The LoRaWAN ensures reliable bidirectional data transmission. Since the available bandwidth of the LoRaWAN is extremely limited, a custom data binary encoding scheme was developed for uplink and downlink data packets (see Fig. 4). The uplink data consist of probe readings, battery voltage, GPS coordinates and various status flags. To conserve power, GPS is not read every device sample period. To minimize time on air, a custom encoding scheme was chosen over different LoRaWAN virtual ports for distinct data types. Every message must have a LoRaWAN header, compressing all the data into a single LoRaWAN message, and only one header must be sent. Virtual will be beneficial if the message length exceeds the maximum allowed length of 51 bytes with SF12.

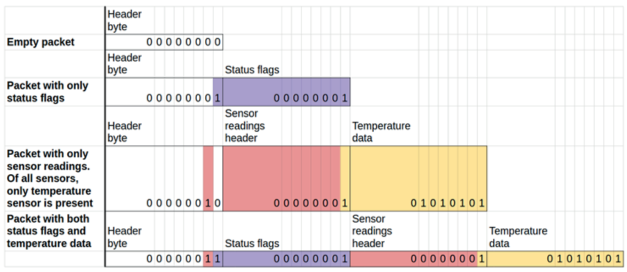

Fig. 4. The structure of the developed communication protocol.

Every packet consists of a header that has eight possible bits set. Each set bit corresponds to a different following section or field in the data packet. The sections are always ordered in correspondence to the following sections whose bit is not set omitted. In turn, every section may either have an additional header for subfields or just the raw data values. This scheme allows adding new top-level data fields to the end of the message without altering the start of the message (except the header field bit). This is an advantageous property in this application since device firmware upgrade over the LoRaWAN network is very problematic.

Each sensor is encoded into a single byte within a valid range. For example, the Dissolved Oxygen value range is 0.25.5 mg/l, which means 0.1 mg/l resolution.

The developed protocol ensures energy-efficient data exchange, allowing one to obtain the autonomous operation of the node through an entire fish-growing period (March–October).

III. Development of Software Components

The information system (IS) of WQMS consists of the following parts – database, backend, frontend, and web service for measurement of data acquisition and set of services for device control (see Fig. 5).

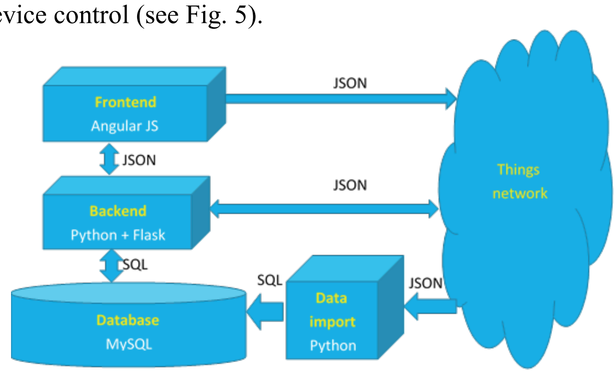

Fig. 5. The interconnections of software components.

All measurement and GPS data from nodes are accumulated by LoRa gateways and forwarded to the LoRaWAN network server through the Cellular (4G) link. The Things Stack (TTS) of the Things Network is used as the network server. According to the subscription, TTS broadcasts data in JSON format to the corresponding web service of the application server. Received data are being written to the local database. Users can keep records of the fish farming enterprise, switch the state of the device, turn the aerator on or off, and observe measurement data with the actions are taken in the pond through the frontend.

A definite level of automation is introduced, as aerators can be turned on or off automatically based on measured data. This is achieved by the system daemon, which regularly launches corresponding stored procedures in the database to decide.

A. Database

Data storage is implemented as a relational database on MySQL basis. It contains a set of technical tables, which are not planned to be modified through frontend interface – users, workstations, types of possible manipulations, physical quantities, and measurement data; a set of classification tables – sensors, nodes, gateways, reservoirs, feeders, aerators, species, diseases, plants, foods; set of tables of instances – nodes, gateways, reservoirs, ponds, feeders, aerators, levels, species, diseases, plants, foods and manipulations.

For every classification table and table of instances, a set of stored procedures is developed – add, delete, get, list, modify.

Storage of measurement data is organized in two levels – measurement timestamps and actual measurement results. For low-latency response, measurements of the last two days are stored additionally in separate tables, which are actualized all the time.

B. Backend

The backend is implemented based on the Python Flask framework. In a unified manner, it allows the corresponding stored database procedure by providing the table name and necessary arguments. For security purposes, JSON Web Token is used. Also, BLOB handling for image writing is realised.

C. Frontend and Web Service

The frontend is based on the Angular framework as it easily adapts the user interface for special cases because of the component-based approach. Menus and corresponding routing of frontend strictly reproduce the structure of the database. The start page map with the placement of nodes and dashboard with the latest measurement results can always be observed (see Figs. 7 and 8). Chart visualization of measurement results with node, calendar, and physical quantity filter follows the dashboard. Also, for alarm cases, visual detection of critical levels of physical quantities entered by users and manipulations done with instances of reservoirs could be shown in the chart. For alternative postprocessing, observable measurement data can be downloaded to an Excel file.

Web service is a simple Python HTTP server with GET and POST methods. Service for data actualization in the last two days, measurements tables and decision-making about device state switching are regularly launched by the system crontab daemon.

IV. Experiments in the Ponds

The system has been deployed in the commercial fish farm Pertnieki near Rezekne, Latvia, for eight months. Six end nodes (blue), two gateways (red) and two aerator controllers (green) have been placed in multiple active ponds (see Fig. 6). It has been ensured that the gateways can receive the data from all sensor nodes and send the downlink messages to the control nodes, switching aerators on/off.

Fig. 6. The locations of nodes and gates in the fishing farm.

A. Measurement Data Representation

All the data obtained during the experiments are stored in the database and represented in various ways.

First, based on the GPS data, the actual position of nodes could be observed on the map together with actual measurement data coming from every node (see Fig. 7).

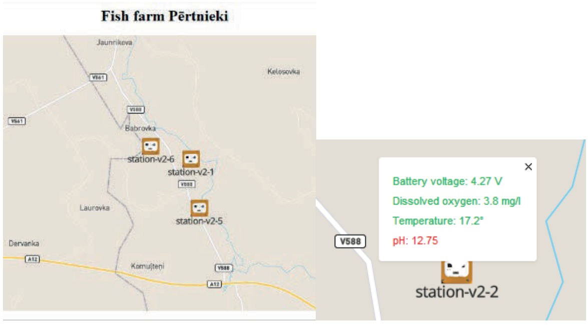

Fig. 7. The locations of nodes on the map with corresponding actual data.

The second way to represent data is the particular dashboard, where the latest values from sensor nodes can be observed. The pre-defined thresholds are automatically applied to sensor data. Values out of range are marked red to indicate the potential issues and the need to provide corresponding actions.

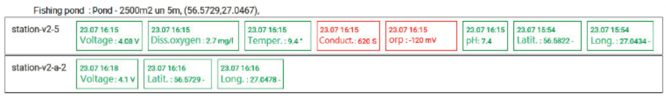

Fig. 8. Dashboard depicting the latest data.

The user interface also allows the study of the historical measurement results with actual thresholds and operation times of all active devices (see Figs. 9 and 10).

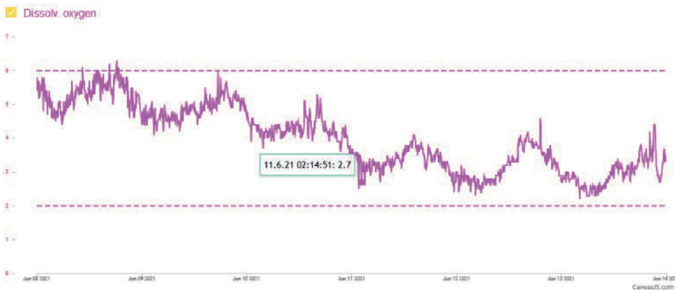

Fig. 9. The level of dissolved oxygen with the corresponding threshold values.

Exemplary data in Fig. 9, representing dissolved oxygen level, allows observing events in different scales. Small-scale events – such as value fluctuation during day-night and large-scale events – define the overall stable oxygen level decrease.

Fig. 10. The operation time of the aerator.

B. Sensor Data Interference Problem

During testing, it has been discovered that the electrochemical water quality probes interfere with each other even when their respective analogue to digital converters are powered off with a load switch. The probes can be seen as voltage sources, and the load switches provide a high impedance path in their off state, not true galvanic isolation. Small residual currents can flow through these switches and common ground connections. The interference manifests as random noise on the measured values of Dissolved Oxygen, pH and ORP values and the direct dependence of the measured parameters on the battery voltage (see Fig. 11).

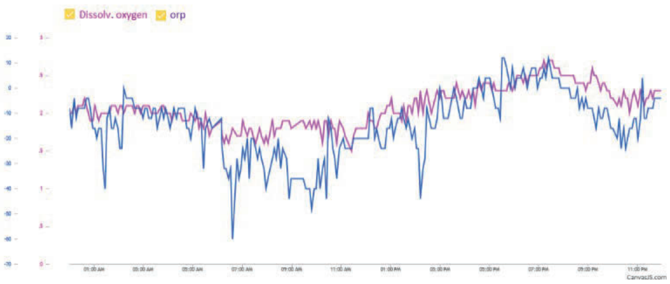

Fig. 11. The evident correlation between dissolved oxygen and ORP data.

To solve this problem, a small interface PCBA has been developed with an ADM3260 digital isolator from Analog Devices to sit between the main node PCBA and probe converter PCBA. It has two bidirectional data lines and an integrated isolated power supply.

Additionally, it has been observed that the water quality probes from Atlas Scientific degrade fast in an active fish pond. They require cleaning and periodic calibration.

V. Conclusions

In this paper, the development of a remote water quality monitoring system has been presented. The system includes all necessary hardware and software components to obtain the data from distant parts of the ponds and provide storage, data processing and control of active devices.

The WQMS has been successfully deployed and tested in various ponds. Results show that it is possible to obtain reliable data on the essential water quality parameters utilizing calibrated low-cost sensors. However, regular maintenance activities (such as cleaning the sensors) should ensure reliable data flow. The developed data exchange protocol allowed obtaining an uninterrupted operation of the data buoy for the whole fish breeding period on a single 18650-type Li-Ion Battery.

Additionally, the study has demonstrated the possibility of automating the operation of aerators deployed in the ponds based on data from dissolved oxygen sensors, thus allowing one to minimize production costs and ensuring uninterrupted control and improvement of vital water quality parameters.

The proposed software and hardware solution can serve as guidelines for developing large-scale IoT solutions at fishing farms and other facilities, requiring permanent and reliable water quality monitoring.

Acknowledgement

The research has been funded by the European Maritime and Fisheries Fund project “The Development of a New Generation of Cyber-Physical Infrastructure for Water Quality Monitoring and Pond Management to Increase the Productivity of Aquaculture Facilities”, No. 18-00-F02201-000003.

This work has been supported by the European Social Fund within project No 8.2.2.0/20/I/008 “Strengthening of PhD Students and Academic Personnel of Riga Technical University and BA School of Business and Finance in the Strategic Fields of Specialization” of the Specific Objective 8.2.2 “To Strengthen Academic Staff of Higher Education Institutions in Strategic Specialization Areas” of the Operational Programme “Growth and Employment”.

References

[1] D. C. Little, R. W. Newton, and M. C. M. Beveridge, “Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential,” *Proceedings of the Nutrition Society*, vol. 75, no. 3, pp. 274–286, 2016. https://doi.org/10.1017/S0029665116000665

[2] A. Litvinenko and E. Bekeris, “Probability distribution of multiple-access interference in chaotic spreading codes based on DS-CDMA communication system,” Elektronika ir Elektrotechnika, vol. 123, no. 7, pp. 87–90, Sep. 2012. https://doi.org/10.5755/j01.eee.123.7.2380

[3] D. D. Anstrangs, D. Cirjulina, R. Babajans, S. Tjukovs, and A. Litvinenko, “Encoded chaos shift keying communication system,” in *2020 IEEE Microwave Theory and Techniques in Wireless Communications (MTTW)*, vol. 1, Riga, Latvia, 2020, pp. 243–248. https://doi.org/10.1109/MTTW51045.2020.9245048

[4] Y. Atoum, S. Srivastava, and X. Liu, “Automatic feeding control for dense aquaculture fish tanks,” *IEEE Signal Processing Letters*, vol. 22, no. 8, pp. 1089–1093, Aug. 2014. https://doi.org/10.1109/LSP.2014.2385794

[5] C. Encinas, E. Ruiz, J. Cortez, and A. Espinoza, “Design and implementation of a distributed IoT system for the monitoring of water quality in aquaculture,” in *2017 Wireless Telecommunications Symposium (WTS)*, Chicago, IL, USA, Apr. 2017, pp. 1–7. https://doi.org/10.1109/WTS.2017.7943540

[6] Y. Ma and W. Ding, “Design of intelligent monitoring system for aquaculture water dissolved oxygen,” in *2018 IEEE 3rd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)*, Chongqing, China, Oct. 2018, pp. 414–418. https://doi.org/10.1109/IAEAC.2018.8577649

[7] T. Abinaya, J. Ishwarya, and M. Maheswari, “A novel methodology for monitoring and controlling of water quality in aquaculture using Internet of Things (IoT),” in *2019 International Conference on Computer Communication and Informatics (ICCCI)*, Coimbatore, India, Jan. 2019, pp. 1–4. https://doi.org/10.1109/ICCCI.2019.8821988

[8] M. Lafont, S. Dupont, P. Cousin, A. Vallauri, and C. Dupont, "Back to the future: IoT to improve aquaculture: Real-time monitoring and algorithmic prediction of water parameters for aquaculture needs," in *2019 Global IoT Summit (GIoTS)*, Aarhus, Denmark, Jun. 2019, pp. 1–6. https://doi.org/10.1109/GIOTS.2019.8766436

[9] K. S. S. Javvaji and M. A. Hussain, "Prototype of aquaculture using IoT technologies," In *2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, Kharagpur, India, Jul. 2020, pp. 1–4. https://doi.org/10.1109/ICCCNT49239.2020.9225519

[10] K. R. S. R. Raju and G. H. K. Varma, "Knowledge-based real-time monitoring system for aquaculture using IoT," in *2017 IEEE 7th international advance computing conference (IACC)*, Hyderabad, India, Jan. 2017, pp. 318–321. https://doi.org/10.1109/IACC.2017.0075

[11] J.-H. Chen, W.-T. Sung, and G.-Y. Lin, "Automated monitoring system for the fish farm aquaculture environment," in *2015 IEEE International Conference on Systems, Man, and Cybernetics*, Hong Kong, China, Oct. 2015, pp. 1161–1166. https://doi.org/10.1109/SMC.2015.208

Dmitrijs Pikulins received his Doctoral degree in Electronics from Riga Technical University in 2012. He is an Associate Professor and a Senior Researcher at the Institute of Radioelectronics, Riga Technical University, Latvia. Moreover, Dmitrijs is an expert at the Latvian Academy of Sciences, a member of RTU Constitutional Assembly and the Head of the Institute of Radioelectronics. His research interests include wireless sensor networks, IoT, nonlinear chaotic systems, power electronics.

Contact information: 12–221 Azenes Str., Riga, LV-1048, Latvia.
E-mail: dmitrijs.pikulins@rtu.lv
ORCID iD: https://orcid.org/0000-0002-6768-6989

Tatjana Solovjova received the diploma of BSc. ing. in 2002, diploma of MSc. ing. in 2004 from Riga Technical University, studied at the post-graduate course in 2004–2007 at Riga Technical University. She has been an Assistant since 2004, a scientific assistant since 2007 and a researcher since 2011 at Riga Technical University, Faculty of Electronics and Telecommunication. Solovjova has co-authored 5 journal papers. Her current research interests include complex permittivity of dielectric materials measuring at microwave frequencies in free space, analytical and numerical investigation of electromagnetic waves propagation and diffraction.

Contact information: Faculty of Electronics and Telecommunication of Riga Technical University, 12 – 427 Azenes Str., Riga, LV-1048, Latvia.
E-mail: Tatjana.Solovjova@rtu.lv

Roberts Gotlaufs earned a BSc. ing. degree followed by an MSc. ing. degree (Honours) in Electrical Science from Riga Technical University in 2018.

He is currently working as an Embedded Software Engineer at SAF Tehnika JSC developing IoT solutions using LoRa networks. Parallel to that, Roberts has a part-time position of Research Assistant at Riga Technical University teaching LoRaWAN fundamentals and developing experimental IoT devices. His professional interests are the latest trends in microcontroller programming, low power design, machine-to-machine communication and embedded device fleet management.

Contact information: 12–426Azenes Str., Riga, LV-1048, Latvia.
E-mail: roberts.gotlaufs@rtu.lv

Arturs Aboltins received his PhD in Electronics and Telecommunications from Riga Technical University in 2013. Before pursuing the doctoral degree, A. Aboltins has held technical and management positions in the industry for more than ten years. He is a Senior Researcher at the Institute of Radioelectronics and an Associate Professor and Head of the Department of Electronics Fundamentals of RTU. His research interests include underwater acoustics, the applications of unitary transforms and software-defined radio. He is the founder and organiser of scientific conferences "Advances in Wireless and Optical Communications (RTUWO)" and "Workshop on Microwave Theory and Techniques in Wireless Communications (MTTW)". He is the Chair of the IEEE Latvia Section Communications, Microwave Theory and Techniques, Antenna and Propagation Joint Societies Chapter.

Contact information: 12 Azenes Str., Riga, LV-1048, Latvia.
E-mail: arturs.aboltins_1@rtu.lv
ORCID iD: http://orcid.org/0000-0001-6901-9787

Juris Grizāns received diploma of MSc. Ing. in Electronics from Riga Technical University in 2005. His current research interests are embedded systems programming, mechanical engineering.

Since 2017, J. Grizāns has been working as a Researcher at the Institute of Radioelectronics, Riga Technical University. His main responsibilities are real-time embedded system design. Additionally, J. Grizāns works as an Assistant Professor at the Faculty of Electronics and Telecommunication of Riga Technical University (RTU). At TU, J. Girzāns participates in several research projects, reads lectures on electronics, MCU programming and related subjects, and is currently working towards receiving his PhD degree.

Contact information: Faculty of Electronics and Telecommunication of Riga Technical University, 12–217 Azenes Str., Riga, LV-1048, Latvia.
E-mail: Juris.Grizans@rtu.lv

Sandis Migla received the diploma of BSc. ing. degree in Electrical Science from Riga Technical University in 2021. He has been a Research Assistant at the Institute of Radioelectronics of Riga Technical University since 2020. He has co-authored one research paper. His current research interests include image processing and use of field programmable gate arrays for implementation of compressed sensing reconstruction algorithms.

Contact information: Faculty of Electronics and Telecommunications of Riga Technical University, 12 Azenes Str., Riga, LV-1048, Latvia.
E-mail: sandis.migla@rtu.lv