THE APPLICABILITY OF ARDUINO MICROCONTROLLER WITH A LORA SHIELD AS AN ELEMENT IN IOT

Primož Podržaj, Tomaž Požrl, Marjan Jenko, Luka Selak, Gašper Škulj, Lidija Rihar, Rok Vrabič, Drago Bračun, Tomaž Berlec and Dominik Kozjek

Faculty of Mechanical Engineering, University of Ljubljana, Ljubljana, Slovenia

ABSTRACT

In this paper an IoT application of LoRa is presented. The application is related to the so-called precision beekeeping. This term is associated with the monitoring of many variables within a hive and in its vicinity, which can assist the beekeeper at all the activities that have to be done in beekeeping practice. In order to achieve that kind of functionality the so called wireless sensor network has to be realized. First an overview of such technologies is given. Our decision was to take LoRa. The core of the system is an Arduino microcontroller with the addition of the LoRa shield. In the paper a process of communication between master and slave unit is described. In order to demonstrate the applicability, the slave unit has an additional temperature sensor attached. The system was verified by a successful temperature measurement lasting several days.

KEYWORDS

IoT, LoRa, Arduino, Beekeeping, Temperature measurement

1. INTRODUCTION

Internet of Things (IoT) describes a concept in which devices, typically equipped with some kind of sensors and data processing capability, exchange information with other devices over internet or some other network. These devices are often called sensor nodes and used to measure various variables associated with physical phenomena like temperature, pressure, humidity, etc. Network formed by these sensor nodes is called wireless sensor network (WSN). Although a permanent progress is being made in the capabilities of WSNs, some challenges still persist [1]:

1. **Energy:** IoT sensor devices are typically powered by batteries. There is a need to eliminate redundant data or aggregate sensor readings.
2. **Self-Management:** ad-hoc deployment of IoT sensors (many sensor networks are deployed without design).
3. **Unattended Operation:** self-organization, self-optimization, self-protection, and self-healing.
4. **Multi-hop Communication:** signal attenuation, increased latency, radio range etc.
5. **Design Constraints:** lack of I/O components such as GPS receivers, Centralized vs decentralized management.

David C. Wyld et al. (Eds): SIPM, ITCA, CMIT, FCST, CoNeCo, SAIM, ICITE, ACSIT, SNLP - 2023
pp. 21-31, 2023. CS & IT - CSCP 2023 DOI: 10.5121/csit.2023.130903

6. **Security:** conventional security techniques often not feasible due to their computational, communication, and storage requirements.

In order for the specific IoT solution to be optimal for the user the correct IoT Network Protocol has to be chosen. They can roughly be divided in three groups as shown in Figure 1.

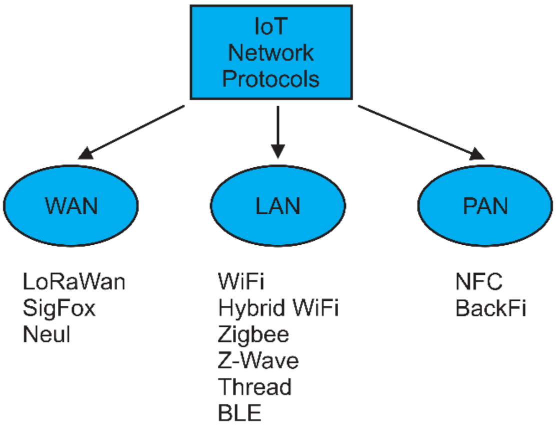

Figure 1. Common IoT network protocols [2]

Wide Area Networks (WAN) cover protocols which allow communications in the range up to several tens of kilometers. Local Area Networks (LAN) is a group of protocols usually targeted at home automation, or industrial process control, with ranges typically around the 100 m range [2]. Personal Area Networks (PAN) is a group of protocols which cover a range of 1m or less. Although range is one of the most important parameters of concern, when defining the appropriate IoT protocol, the maximum rate of data transfer might be at least equally important in some cases. An overview of IoT protocols with respect to both the range and the data rate is given in Figure 2.

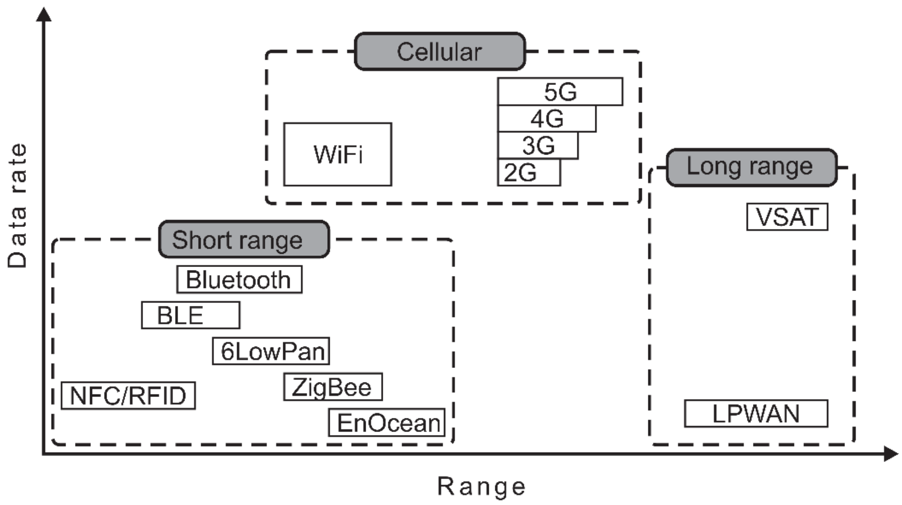

Figure 2. Comparison between various communication protocols in IoT [3]

It can be seen that the majority of high data rate protocols are concentrated in the medium range. These protocols are based on cellular technologies. The most commonly known is WiFi and 4G. Short range protocols are sometimes interesting for IoT applications. Although NFC/RFID, which is placed at the shorter-range end, is difficult to imagine in any real life IoT scenario, protocols such as Bluetooth and Zigbee might be interesting. The long-range group is based on two technologies. Very Small Aperture Terminal (VSAT) is a satellite-based technology which is simply to cumbersome and expensive to be used in the vast majority of IoT applications, despite having a good data rate. Low power wide area network (LPWAN) on the other hand might be a very interesting alternative. It has significantly lower data rate, but it is also much less cumbersome, cheaper and uses less power. And the last, but not least, the cost is very important.
A more detailed comparison of several protocols is given in Table 1. They were chosen based on the fact that IoT applications often don't require high data rate. Instead, it is very important that the range suits the application. Often, the power requirement should also be low, especially if the device is power is supplied by a battery.

Table 1.Comparison between Zigbee, Sigfox, LoRa, WiFi HaLow and BLE [4]

Features	**Zigbee**	**Sigfox**	**LoRa**	**WiFi HaLow**	**BLE**
Freq. band	2.4 GHz	902 MHz (US) 868 MHz (EU)	902-928 MHz (US) 434-863 MHz (EU) 490 MHz (CH)	902-928 MHz	2.4-2.483 GHz
Num. of channels	1-10-16 channels	360 channels	80 channels (US) 10 channels (EU)	26 channels	40 channels
Chan. bandwidth	-	100-1200 Hz	125 kHz (US) 250 kHz (EU)	100 kbit/s	2.4 GHz
Max. data rate	20-250 kbps	100-600 bps	250-50 kbps	Up to 8.67 Mbit/s	1 Mbit/s
Battery life	2.5 years	<10 years	<10 years	3 years	-
Cost	Low	Low	Very low	Low	Low

When studying the protocols, we had a beekeeping application in mind. Precise beekeeping is a term associated with a detailed monitoring of several parameters related to a beehive and the bee colony. At first our goal was to develop a solution which would enable the beekeeper to monitor temperature in several beehives at once. They might be scattered across a wider area. The schematic representation of the solution is shown in
Figure 3.

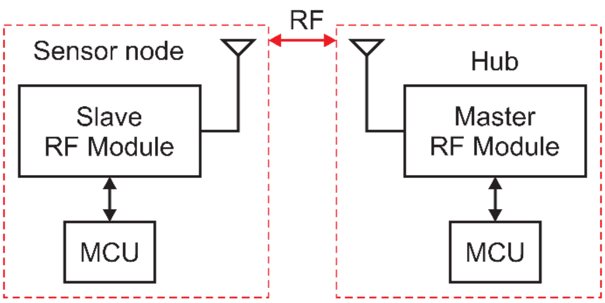

Figure 3. Master - slave communication [5]

Of course, in our case there would be one master and many slaves. Our ultimate goal would be to connect these beehives together and then one of them which would be acting as a master would be sending the data to a beekeeper. But at this stage, we just wanted to realize the communication between different beehives. As our application doesn't need a high data rate, but needs good autonomy and especially low costs, LoRa was the protocol we have chosen.

2. LORA

Low Power Wide Area Networks (LPWAN) received attention because of its characteristics covering a large geographical area for low power, low cost and low data rate devices, when compared to ZigBee, Bluetooth, Z-Wave, WiFi and NFC. LoRa stands for "Long Range", communication protocol designed for LPWAN, low consumption and long-range use star or mesh topology which rises battery life [4]. The LoRaWAN Regional Parameters specification defines the adaptation of the LoRaWAN Link Layer specification to comply with the various regulations enforced throughout the world on the use of various frequency bands of unlicensed spectrum which are available [6]. Each of the regional channel plans can be broadly characterized as dynamic channel plans, with a small number of default channels, or fixed channel plans, where all the channels are defined and then selectively activated by the network. LoRa frequency bands of some countries are displayed in Table 2.

Table 2. LoRa frequency bands of some countries [7]

Location	**Frequency band [MHz]**	**Channel plan**
Germany (DE)	433.05 - 434.79	EU433
	863 - 870	EU863-870
United Kingdom (UK)	863 - 870	EU863-870
	915 - 918	AS923-3
United States (US)	902 - 928	US902-928
Japan (JP)	920.6 - 928.0	AS923-1
China (CN)	920.5 - 924.5	AS923-1
	779 – 787	CN779-787
	470 - 510	CN470-510
India (IN)	865-867	IN865-867
Slovenia (SI)	433.05 - 434.79	EU433
	863 – 873	EU863-870
	915 - 918	AS923-3

The LoRa protocol is defined on the link-layer level (see Figure 4) and is proprietary, therefore not all the information is freely available. Nevertheless, it is known that due to the used Chirp Spread Spectrum (CSS), the power consumption does not depend on the content of the data, but only on the so-called time on air (ToA) and the output power [8].

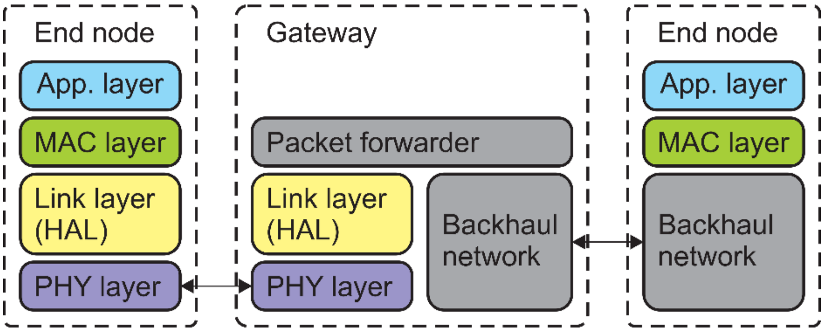

Figure 4. IoT Architecture [9]

In general, the analysis of the power consumption of the IoT devices can be divided into several phases (see Figure 5). The first division is into "active" and "sleep" modes. The relation between the two of course depends on the application, but if this discussion is to be taken under consideration, the duration of the sleep mode needs to be much longer than the duration of the active mode. Typically, the IoT device operates in periodic "active" and "sleep" mode configuration.

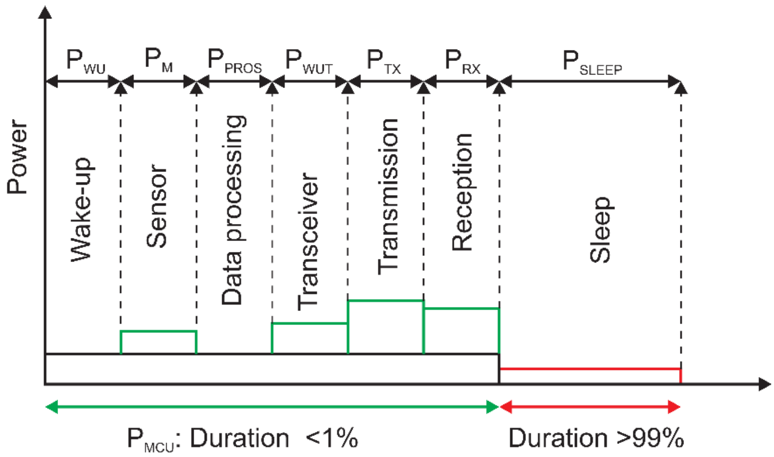

Figure 5. Power consumption model of sensor node

The total consumption of energy within one cycle is equal to:

$$E_{cycle} = P_{active} \cdot T_{active} + P_{sleep} \cdot T_{sleep}$$

The active mode is further divided into several phases [10]:

1. Wake up P_{wu}
2. Measurements by the sensor P_m
3. Data processing P_{proc}
4. Wake up of the radio module P_{wut}
5. Data transmission P_{tx}
6. Data reception P_{rx}

In general, the electric currents associated with the "active"' mode should be in mA range, whereas the currents associated with the "sleep" mode should be in the µA range although in reality, higher currents are often measured [8]. The advantages of the "sleep" mode of course increase with the percentage of total time spent in this mode. This is of course heavily application dependent. Some applications using LoRa protocol are:

1. Unmanned Aerial Vehicle Based for Marine-Coastal Environment Monitoring [11]
2. Precision agriculture [12]
3. Smart parking [13]
4. Street light automation [13]
5. Renewable Energy Monitoring System [14]
6. Monitoring of Patient's SPO2 and Heart Rate [15]

In our case the application could also be called precision agriculture. But to be more exact it is about precision beekeeping.

3. EXPERIMENT

In Slovenia, various types of beehives are being used, but the most common are the ones called "AŽ" beehives shown in Figure 6. They are often located on a single spot, typically in a hut with a roof.

Figure 6. Most common beehives in Slovenia

Globally speaking, the so called Langstroth hives (see Figure 7) are more popular. These hives can be located in a more concentrated manner or widely dispersed in a possibly forested area. The LoRa with its long range and low power requirement seemed to be a good solution to be used for precision beekeeping in such a scenario.

Figure 7. Langstroth hives

In order to verify the applicability of wireless LoRa connectivity an experiment was prepared in which the goal was to measure the temperature remotely. The sensor used for this purpose was LM35 with the sensitivity of 10 mV/°C. The client side of the system was composed of the Arduino Due microcontroller and the Dragino LoRa shield v1.3 in addition with an antenna as shown in Figure 8. The schematic representation of the same system is shown in Figure 9.

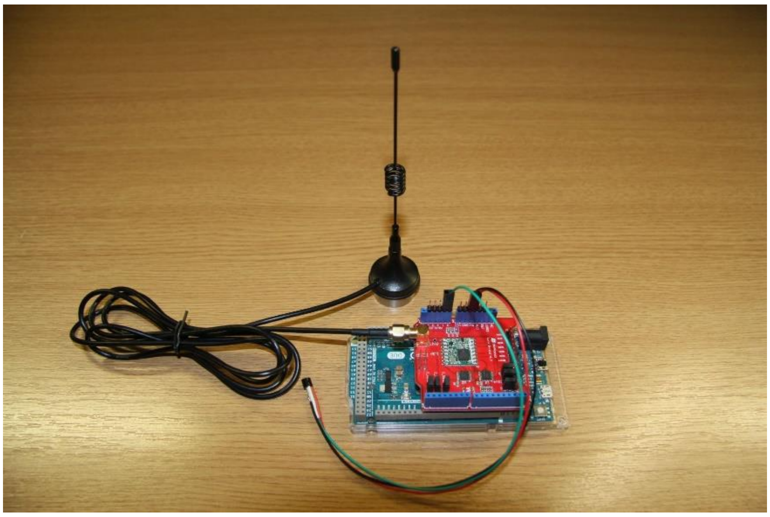

Figure 8. Arduino Due with Dragino LoRa shield and antenna

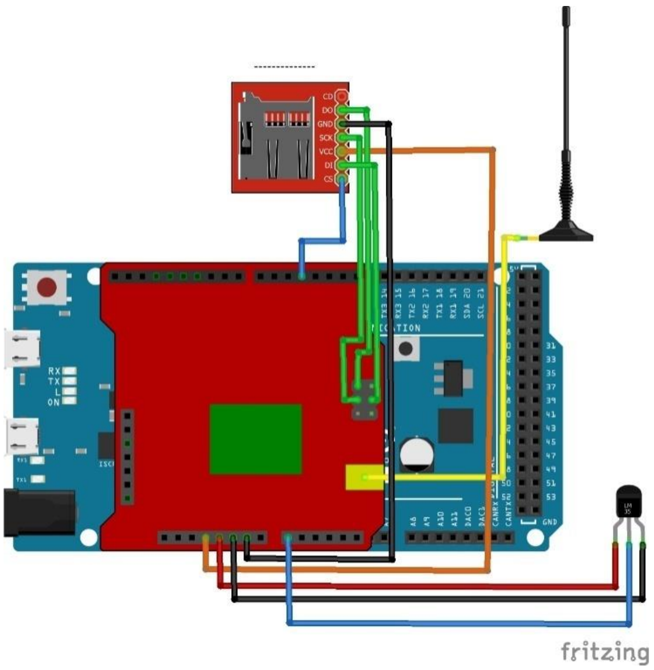

Figure 9. The schematic representation of the slave

A similar setup was used also on the master side of the system, in this case without a temperature sensor. The programming of both, the client and server-side Arduino microcontrollers, was executed in Arduino IDE. The first step that has to be made is the addition of a proper library.

We have used the library “RadioHead-1.121” [16]. When it is imported into Arduino IDE, example sketches for both the client and the server are made available. The examples are designed to send one byte (8-bit) packages. In our case a temperature reading was obtained using a 10-bit AD conversion, therefore information had to be sent in two packages, which were formed using the following code:

```
temperature1 = analogRead(A0);
byte tmp1_H = temperature1 >> 8;
byte tmp1_L = temperature1;
```

On the receiving end the following code has to be added:

```
temperature1 = ((buf[0] << 8) + buf[1]) * 3.33 / 1023 * 100.0;
```

It makes a 16-bit value out of two 8-bit packages. Then this is multiplied by 3.33 (ADC reference voltage), divided by 1023 (value related to 10-bit conversion) and divided by 0.01, which is the same as multiplied by 100, which is the sensor sensitivity.

In operation, the following type of message can be seen on the Serial Monitor for the client:

```
Sending to rf95_server
got reply: Received
```

In case of the Server, the following information is displayed:

```
Temperature: 25.72 C
Sent a reply
```

The system was successfully tested in a real environment. As an example, a temperature profile obtained by a measurement lasting several days is shown in Figure 10.

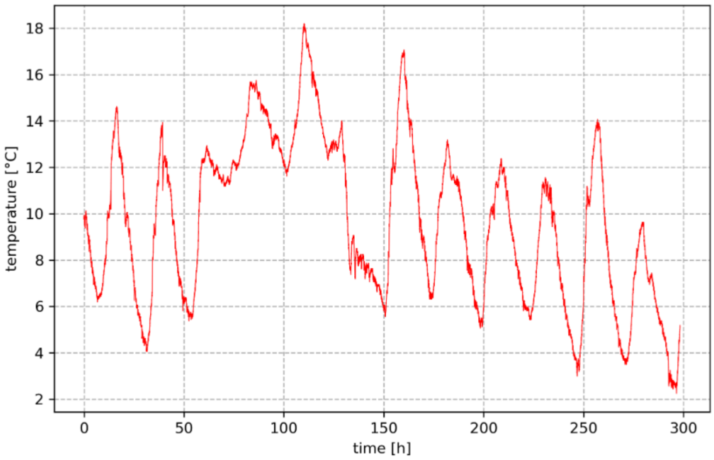

Figure 10. An example of the temperature profile

The oscillations due to night and day variations in temperature can be clearly seen. Some more abrupt variations are attributed to rainstorms.

4. Conclusion

In this paper an application of an Arduino microcontroller with a LoRa shield is presented. It was selected in order to present the applicability of modern IoT technologies for smart beekeeping. In our case the application was a remote temperature measurement. If needed, other environment variables or parameters related to honey production or bee colony health could be measured as well. As the solution is scalable it can easily be implemented on multiple beehives at once. Beside that, the system could also be easily used for any other IoT applications that require low power and long-range communication.

References

[1] M. Elkhodr, S. Shahrestani and H. Cheung, "Emerging wireless technologies in the internet of things: a comparative study," arXiv preprint arXiv:1611.00861, 2016.

[2] P. Barker and M. Hammoudeh, "A survey on low power network protocols for the internet of things and wireless sensor networks," in Proceedings of the international conference on future networks and distributed systems, 2017, pp. 1-8.

[3] K. Mekki, E. Bajic, F. Chaxel and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," ICT express, vol. 5, pp. 1-7, 2019.

[4] B. Alqahtani and B. AlNajrani, "A Study of Internet of Things Protocols and Communication," in 2020 2nd International Conference on Computer and Information Sciences (ICCIS), IEEE, 2020, pp. 1-6.

[5] A. Dementyev, S. Hodges, S. Taylor and J. Smith, "Power consumption analysis of Bluetooth Low Energy, ZigBee and ANT sensor nodes in a cyclic sleep scenario," in 2013 IEEE International Wireless Symposium (IWS), IEEE, 2013, pp. 1-4.

[6] D. Kjendal, "LoRa-Alliance Regional Parameters Overview," Journal of ICT Standardization, pp. 35-46, 2021.

[7] RP002-1.0.1 LoRaWAN Regional Parameter, LoRa Alliance Technical Committee Regional Parameters Workgroup, 2020.

[8] E. Bäumker, A. M. Garcia and P. Woias, "Minimizing power consumption of LoRa® and LoRaWAN for low-power wireless sensor nodes," in Journal of Physics: Conference Series, 2019.

[9] C. Li and Z. Cao, "Lora networking techniques for large-scale and long-term iot: A down-to-top survey," ACM Computing Surveys (CSUR), vol. 55, pp. 1-36, 2022.

[10] K. R. Rao, K. D. Sateesh, M. Shaw and V. Sitamahalakshmi, "Energy Efficiency Analysis of LoRa and ZigBee Protocols in Wireless Sensor Networks," REVISTA GEINTEC-GESTAO INOVACAO E TECNOLOGIAS, vol. 4, pp. 2836-2849, 2021.

[11] C. A. Trasvina-Moreno, R. Blasco, A. Marco, R. Casas and A. Trasvina-Castro, "Unmanned aerial vehicle based wireless sensor network for marine-coastal environment monitoring," Sensors, vol. 17, p. 460, 2017.

[12] X. Feng, F. Yan and X. Liu, "Study of wireless communication technologies on Internet of Things for precision agriculture," Wireless Personal Communications, vol. 108, pp. 1785-1802, 2019.

[13] S. Devalal and A. Karthikeyan, "LoRa technology-an overview," in 2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), 2018.

[14] C.-S. Choi, J.-D. Jeong, I.-W. Lee and W.-K. Park, "LoRa based renewable energy monitoring system with open IoT platform," in 2018 international conference on Electronics, Information, and Communication (ICEIC), 2018.

[15] P. D. P. Adi and A. Kitagawa, "A Study of LoRa Performance in Monitoring of Patient s SPO2 and Heart Rate based IoT," International Journal of Advanced Computer Science and Applications (IJACSA), vol. 11, pp. 238-251, 2020.

[16] "RadioHead Packet Radio library for embedded microprocessors," [Online]. Available: http://www.airspayce.com/mikem/arduino/RadioHead/}. [Accessed 16 2 2022].

AUTHORS

Primož Podržaj received the M.Sc. degree and the Ph.D. degree in automatic control from the University of Ljubljana, Ljubljana, Slovenia, in 2000 and 2004, respectively. He is now a Professor with the Faculty of Mechanical Engineering, University of Ljubljana. His research interests include signal and image processing, control systems, control system design, and industrial automation.

Tomaž Požrl received the B.Sc. and Ph.D. degrees in electrical engineering from the University of Ljubljana, Slovenia, in 2005 and 2012, respectively. He is currently a Teaching Assistent with the Faculty of Mechanical Engineering, University of Ljubljana. His research interests include control systems, industrial automation, artificial intelligence, and recommender systems.

Marjan Jenko (Member, IEEE) received the M.Sc. E.E. degree from the University of Ljubljana, in 1987, and the Ph.D. E.E. degree from Boston University, Boston, in 1994. He started his career at the Iskra Microelectronics Division in Ljubljana. A year after becoming the Head of the IC Design Department, he went to Boston to pursue the Ph.D. studies. After his studies, he joined RF Power Products Inc., Voorhees, NJ, as a Research Engineer. Later, he joined System Chip, Los Gatos, CA, as a VLSI Designer. He has been with the University of Ljubljana, since 2000. He has been teaching electric circuit theory and programming engineering for the last ten years. He has been developing multi discipline projects for the education of engineering, IT, and product design students. His current work encompasses the design and optimization of product and manufacturing parameters for robust production of in-wheel electric motors. His research fields include embedded systems, control theory, distributed applications for management and control, methods of design for robust production, algorithms for process simulation, and technical education. Dr. Jenko received two golden awards for industrial innovation from the Chamber of Commerce and Industry of Slovenia, in 2003 and 2005, where he received a silver award for an industrial innovation, in 2014.

Luka Selak received a Ph.D. degree in Mechanical Engineering from the University of Ljubljana in 2014. He is a teaching assistant in the Laboratory for Mechatronics, Production systems, and Automation, LAMPA. His current research interests include data acquisition systems, wireless sensor networks, SCADA systems, data mining and fault diagnostics.

Gašper Škulj received his Ph.D degree from the Faculty of Mechanical Engineering, University of Ljubljana, in 2016. He is an assistant professor with the Laboratory for Mechatronics, Production systems, and Automation (LAMPA), Faculty of Mechanical Engineering, University of Ljubljana. His research interests include mechatronic systems, robotics, distributed systems and advanced production systems, with emphasis on self-organisation.

Lidija Rihar graduated from the Faculty of Mechanical Engineering in Ljubljana in 2009 in the field of production systems. In 2013, she defended her doctoral dissertation entitled Generalized model of concurrent product and process development. Since 2013 she has been a research associate at the Faculty of Mechanical Engineering in the field of production systems.

Rok Vrabič, Ph.D., Asst. Prof. is a lecturer at the Faculty of Mechanical Engineering, University of Ljubljana. His research focuses on mechatronics, robotics, and artificial intelligence. He is an author of 22 publications in top scientific journals and 30 papers at international conferences. He is an associate member of CIRP, the International academy for production engineering.

Drago Bračun is researcher and assistant professor at the Faculty of Mechanical engineering, University of Ljubljana. He is interested in the application of advanced vision systems in monitoring, diagnostics and prognostics of systems and processes. These include 3D body shape measurement based, visual inspection of parts, CNC and robot localization systems and visual monitoring of welding processes.

Tomaž Berlec, Ph.D. is an assistant professor at Faculty of Mechanical Engineering, University of Ljubljana. He made his M. Sc. degree in 2003 and Ph.D. degree in 2008 in the field of production planning and control. His research fields include: lean production, agile and leagile production, simulation, project management, material and information flow optimization, lead times optimisation of operations and orders, production planning and control. In these fields, he published 29 original scientific papers in scientific journals.

Dominik Kozjek received the B.S. degree in mechanical engineering, the M.S. degree in mechatronics and laser technology, and the Ph.D. degree in production engineering sciences, cybernetics, and mechatronics from the University of Ljubljana. He is a researcher in mechatronics, production systems, and automation with the University of Ljubljana and a postdoctoral scholar in advanced manufacturing processes with Northwestern University in the United States. His research focuses on applications of artificial intelligence in mechanical engineering, data analytics, additive manufacturing, and robotics. He is a research affiliate at the international academy for production engineering CIRP.