

LONG-RANGE REMOTE CONTROL BASED ON LORA TRANSCIVERS

Enes Saletović^{1,2}, Nevzudin Buzadžić¹, Đulaga Hadžić¹

Abstract: Within this paper, the possibility of using advanced LoRa technology in the field of long-range remote control was considered. For testing purposes, a one-way point-to-point LoRa remote control link was implemented based on the LoRa Ra-02 SX1278 transceiver and the corresponding 32-bit Cortex-M3 microcontroller. The remote control application software is developed in the Arduino development environment. The implemented link was tested experimentally to check the range, data transfer speed and link stability. Test results show that LoRa transceiver modules can be used in the field of long-range remote control.

Keywords: LoRa, transceivers, long-range, remote, control, point-to-point, link

INTRODUCTION

Remote control means controlling remote objects or processes, most often wirelessly, using electromagnetic waves from the open ISM (Industrial, Scientific, Medical) frequency spectrum. National laws precisely define the free ISM frequency bands as well as the permitted emission power. Limited emission power reduces interference on ISM bands, but limits remote control range. The remote control as well as the remote-controlled object, are usually powered by autonomous batteries. LoRa (Long Range) is a spread spectrum modulation technology derived from Chirp Spread Spectrum (CSS) technology [1], published in 2015. It is a long-range, low-power wireless technology that has become one of the most popular platforms of the Internet of Things (IoT). LoRa transceivers enable two-way communication using their communication protocol. LoRa transceiver modules most often communicate on the ISM frequency bands 433, 866 and 915 MHz, according to the national legal regulations.

LoRa technology enables remote control over longer distances using low-emission power [2]. Like competing low-power technologies, LoRa technology has a limited communication speed that usually ranges from 64 to 300 kbps. LoRa transceiver modules are widely used in data acquisition systems in industry and agriculture [3]. Modern LoRa modules enable higher data transfer speed with resistance to interference from the environment, so they are increasingly used in the field of industry [4] and remote control [5]. Data transmission is carried out via several LoRa communication channels on the ISM frequency range. The reliability of the communication link is increased by using a 256-bit control CRC (Cyclic Redundancy Check) code. The security of packet data transmission is achieved

by the encryption method. By connecting multiple LoRa modules, a LoRa WAN (Wide Area Network) can be formed for centralized data collection and processing. Compared to competing LPWAN (Low Power Wide Area Networks) technologies, LoRa technology enables a greater range measured in kilometres, with low power consumption. For example, standard Wi-Fi networks provide better data transfer speeds, but the communication range is limited to short distances indoors and several hundred meters outdoors.

The motives for researching the possibility of applying advanced LoRa technology in the field of long-range remote control are:

- LoRa is a new and promising technology,
- LoRa transceivers are cheap and available,
- The possibility of practical application in the field of long-range remote control,
- Deepening knowledge in the field of long-range remote control systems.

The research presented in this paper aims to verify whether modern available LoRa transceivers can be used to implement a long-range remote control system, taking into account issues such as connection stability, range, data rate, immunity to interference, power consumption and cost. After this introduction, the paper contains five chronologically connected sections. Section 1 provides an overview of the background and related works. Section 2 describes the research methodology including experiment setup. Section 3 provides experimental results, discussion and guidelines for possible future research. Chapter 4 provides conclusions regarding the application of LoRa transceivers in the field of long-range remote control.

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1. BACKGROUND

In general, remote control is implemented as a two-way or one-way point-to-point (master-slave) connection between a remote control (transmitter) and a controlled object (receiver) such as a robot and UAV (Unmanned Aerial Vehicle). Remote control is performed in real-time, so it is necessary to ensure a stable connection in real conditions in the presence of interference from the environment. Interference intensity is usually higher in urban areas due to the greater number of wireless networks and devices. The required performance of a remote control link usually includes range, data rate, link stability, power consumption, price and link maintenance costs. Based on the required performance of the remote control link, it is necessary to select a suitable transceiver module as well as a suitable microcontroller that should enable programming and implementation of the appropriate application software for remote control. Inside the application software, it is necessary to define parameters like emission power, working channel, data rate, number of packet retransmission attempts, data protection algorithm, etc. Depending on the number of control variables, it is necessary to select appropriate sensors such as joysticks, potentiometers, gyroscopes, switches, etc. Also, based on the estimated power consumption, an appropriate power supply should be chosen. Depending on the type of link, it is necessary to choose appropriate antennas that significantly affect the range and stability of the link. Available LoRa transceivers enable long-range communication with emission power below 1 W. Thanks to available LoRa transceivers, favourable prices, and detailed documentation, various application systems in the field of data acquisition and remote control systems have already been implemented in practice.

The possibility of using LoRa transceivers in the field of remote control has been analysed in several relevant scientific papers. The paper [1] presents the advantages of LoRa technology compared to competing technologies in the field of IoT. In papers [2], [4] and [5], the industrial applications of LoRa transceivers in the field of remote control and monitoring are presented. The paper [3] describes the application of LoRa technology in the field of agriculture. Algorithms for increasing data transmission speed in LoRa LPWAN networks are presented in the paper [6]. In the paper [8], the experimental results of measuring the range of the LoRa transceiver on the ISM band 866 MHz were analysed and the signal propagation diagram was presented. In the paper [9] authors presented a preliminary study for realizing a LoRa-based mesh network, not relying on LoRaWAN, that implements peer-to-peer communication between nodes, without the use of gateways, and extends node reachability through multi-hop communication. In the paper [10], the possibilities of ad-hoc networking of flying objects using LoRa transceivers for the purpose of increasing the range of remote control were analysed. The selection of LoRa modulation parameters is discussed in the paper [11].

2. RESEARCH METHODOLOGY

In the course of the research, the relevant papers published in the last five years dealing with the application of LoRa technology in the field of remote control, as well as the technical documentation available for LoRa transceivers, were analysed. Based on this information, the necessary preparations were made for the experimental verification of the possibility of using modern LoRa transceivers in the field of long-range remote control. Modern LoRa transceivers are procured to implement a LoRa transmitter and receiver in hardware. An experimental research method was used, which, based on multiple measurements, allows for checking the capabilities of the LoRa transceiver in a real environment. A plan for experimental testing of the implemented point-to-point master-slave link, which includes several scenarios for testing and measuring the link performance in urban and suburban environments, was created. The goal of the experimental testing was to examine the LoRa-based remote control link capabilities in terms of:

- Link stability,
- Range in urban and suburban areas,
- Effect of obstacles on connection range,
- Impact of interference on connection range,
- Influence of antenna position.

2.1. Experimental setup

In order to experimentally check the possibilities of LoRa technology in a real environment for data monitoring and remote control, the transmitter and receiver were realized based on a modern and competitive LoRa transceiver module Ra-02 SX1278 433 MHz. The choice of transceiver was made based on the analysis of technical specifications [7] and the experiences of other authors. The LoRa Ra-02 SX1278 transceivers provide ultra-long-range wide-spectrum communications and high immunity to interference with minimal power consumption. It is widely used in applications such as automatic meter reading, home and building automation, industrial monitoring and control, wireless security systems and long-range irrigation systems. Features of the LoRa Ra-02 SX1278 module are:

- Range 10 km (with a clear line of sight),
- Bit rates up to 300 kbps,
- Working frequency band 433 MHz,
- LoRa Spread Spectrum modulation technology,
- High sensitivity: down to -148 dBm,
- Half-duplex SPI communication,
- Shielded housing and spring antenna,
- Supply current in transmit/receive mode 120 mA/12 mA and only 1.6 mA in standby mode,
- 127 dB RSSI (Received Signal Strength Indicator) dynamic range,
- Automatic RF (Radio frequency) signal detection and CAD (Channel Activity Detection) mode, very high-speed AFC (Automatic Frequency Control) and Packet engine with CRC up to 256 B.

Using the LoRa Ra-02 module and the STM32F103C8T6 microcontroller, a one-way point-to-point (master-slave) long-range remote control link is implemented. The connection between the microcontroller and the LoRa transceiver is established via a 4-pin SPI (Serial Peripheral Interface), which can support data rates up to 10 Mbps. The connection method is shown in Table I. Programming of the transmitter and receiver was done using a USB-to-TTL adapter and an ST-Link V2 adapter.

Table I: Connection method

STM32F103C8T6	LoRa SX1278
pin	pin
GND	GND
3.3 V	VCC
PB0	RST
PA5	SCK
PA6	MISO
PA7	MOSI
PA4	NSS
PA1	DI00

The receiver is implemented on a 7x9 cm motherboard, with a microcontroller, voltage regulator, LoRa Ra-02 transceiver with antenna, gyroscope and GPS modem (Figure 1). The total mass of the receiver without battery is 70 grams. The components are densely packed on the motherboard to minimize the overall volume and weight of the receiver. The transmitter is implemented on twice the mainboard because the volume and mass of the remote control are not as critical as in the case of the receiver. Instead of sensors, the transmitter has joysticks, switches and potentiometers, as well as a voltage regulator with a 3S 11.1 V battery. A suitable 3.3 V voltage regulator ensures enough power for all used components on the motherboard.

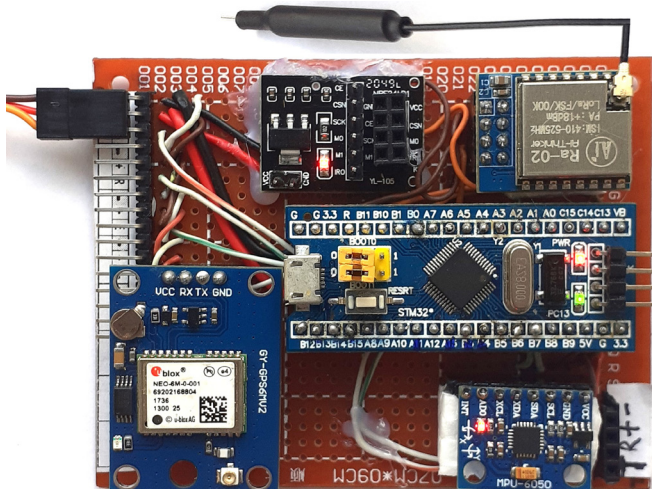


Figure 1: Receiver based on LoRa Ra-02 module

2.2. Remote control unit (transmitter)

Figure 2 shows the block diagram of the remote control unit, which consists of a 32-bit Cortex M3 microcontroller STM32F103C8T6, LoRa transceiver SX1278, sensors, voltage regulator and power supply. Arduino IDE (Integrated Development Environment) was used to develop application software. The necessary libraries (SPI.h and LoRa_STM32.h) containing the necessary functions for managing the LoRa transceiver and the SPI communication interface are included. Within the Arduino remote control application, the maximum possible emission power is set (TxPower = 20). The sensors are connected to the input GPIO (General-Purpose Input/Output) pins of the microcontroller. The analogue values read from the sensors (analogue joysticks) are converted using built-in 12-bit ADC (Analog-to-digital) converters. A USB/serial adapter and Arduino Serial monitor tool were used for the source code debugging and monitoring the status of the transmitter. The transmitter is programmed to read the sensor values and send them to the receiver in the form of data packets. The maximum size of a LoRa SX1278 data packet is 256 bytes. The sensor reading frequency was selected according to the required remote control performance, respecting the maximum possible operating frequency of the microcontroller's ADC converter. The data packet contains a series of 10 decimal numbers that represent the mapped readings from the remote control sensors. The power supply unit contains two standard 3.7 V batteries and a voltage regulator, which provides 3.3 V output and enough power for the transmitter components. All transmitter components use the same voltage of 3.3 V. To reduce the induction of interference on the signal connection lines between the LoRa SX1278 module and the microcontroller, these two main components are located at a minimum distance.

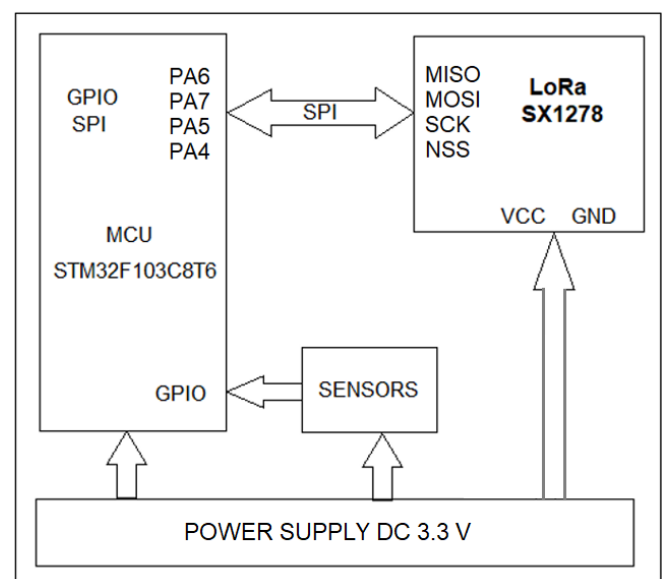


Figure 2: LoRa-based transmitter

2.3. Remote control receiver unit (receiver)

Figure 3 shows the block diagram of the receiver located on the controlled object. The receiver consists of a 32-bit microcontroller STM32F103C8T6, a LoRa SX1278 transceiver, a battery power supply, a suitable voltage regulator and actuators such as servo motors and DC motors. The actuators are connected to the corresponding GPIO pins of the microcontroller and power supply.

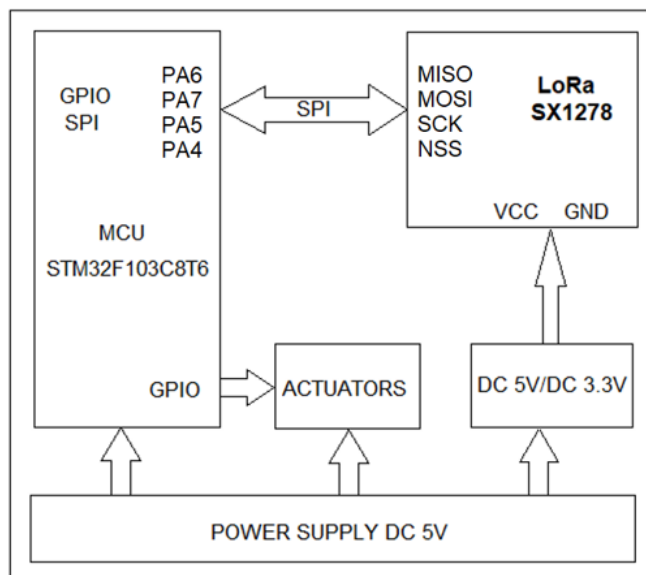


Figure 3: LoRa-based receiver

The receiver application software source code developed in the Arduino IDE development environment is similar to the transmitter source code. The connection parameters are set in the same way as on the transmitter side. On the receiver side, the same channel for data transmission is set as on the transmitter side. To enable online monitoring of the values received from the remote control, the Arduino Serial monitor tool, which allows displaying of the received control values on a laptop computer in real-time, was used on the receiver side. The Serial monitor tool allows easy debugging of application code and real-time experimental application testing.

To enable additional visual monitoring of the packet data reception, a signal LED (Light Emitting Diode), which flashes to signal the reception of data packets, is installed on the receiver side. Using the receiver application software, the control values for each actuator are extracted from the received data packet. The received control values are forwarded to the actuators in order to achieve remote control of the controlled object or process. Data encryption was not used because it partially slows down the data rate. The same factory spring antenna was used on the receiver side. The shield around the communication chip SX1278 reduces interference. Both sides, transmitter and receiver, use the same LoRa modulation parameters, including the maximum output power of the transmitter. All other LoRa modulation parameters have default values.

3. EXPERIMENTAL RESULTS

By the created test plan of the remote control link implemented in the hardware, multiple experimental measurements of the link performance were performed in urban and suburban areas. In both cases, the same hardware was used with the same settings. Link performance testing was performed using the Arduino Serial monitor tool, which provides monitoring of the level of the received signal and recording of the received data packets. The measurement was performed by fixing the transmitter at the selected location while the receiver was moved along the selected route. Factory spring antennas with a gain of 2 dB were used on both sides of the link. The implemented unidirectional point-to-point remote control link was tested in urban and suburban areas in the presence of different wireless networks, to verify the performance of the proposed solution in terms of range, data rate and link stability. The antennas were placed vertically at an angle of 90 degrees. The remote control unit (transmitter) is set to periodically send a sequence of control signals read from the remote control sensors. The receiver was connected to a laptop computer to read the received control signals and monitor the link status. The first measurements were made indoors to test the signal range in the building. After that, the link was tested outdoors by placing the transmitter on the window of the room and moving the receiver around the surrounding city streets. In this way, the remote control of a UAV vehicle was simulated in real conditions in the presence of various disturbances. Using the Arduino Serial monitor tool, the RSSI level of the received signal and the number of the received data packets were monitored. Figure 4 shows a listing of the data packet transfer process on the transmitter side. The listing shows the exact time of sending each data packet as well as the serial number of the packet. By analysing the sequence numbers of the packets and the total number of received packets in a unit of time, the percentage of received packets can be determined.

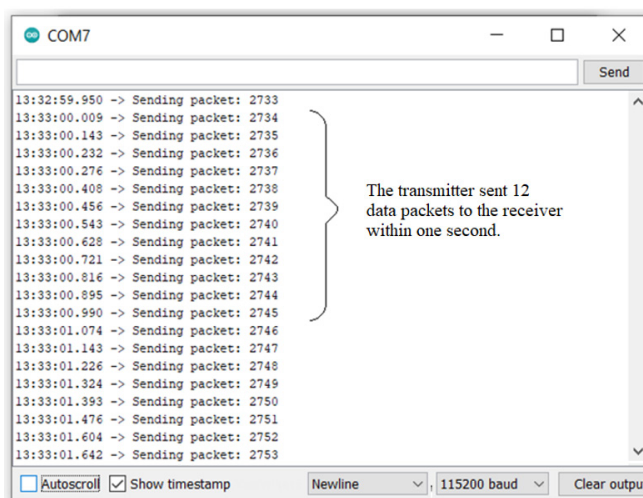


Figure 4: Monitoring of the data packet sending using the Arduino Serial monitor tool

During one second, a total of 12 data packets containing sequences of 10 control variables were transmitted from the transmitter. On the receiver's side, a blinking LED indicated the reception of a data packet. Figure 5 shows a listing of the data packet received from the transmitter. The receiver is moved across an urban city area with tall brick buildings. The level of the received signal when the transmitter and receiver were in the same room or at a short distance without obstacles along the line of sight, was high (RSSI = -65). As the receiver moved away from the transmitter, the signal level decreased faster or slower, depending on the obstacles between the transmitter and the receiver. Brick buildings cause greater signal attenuation. The connection was successfully maintained on routes without optical obstacles.

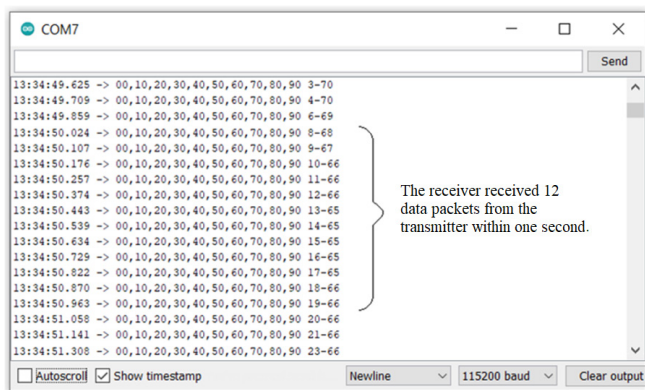


Figure 5: Monitoring of the data packet receiving using the Arduino Serial monitor tool

As the distance to the receiver and the number of obstacles along the link direction increase, the signal level and percentage of received packets decrease. The connection was maintained up to the signal level (RSSI = -115) after which the connection was interrupted. Figure 6 shows the results of measuring the link range in a densely populated urban environment. The fixed position of the transmitter is marked with a blue circle, while the measuring points are marked with green, yellow and red squares, according to the quality of the received signal.



Figure 6: Link range measurement in an urban area with obstacles

The receiver was moved around the transmitter in the surrounding streets. The green squares in Figure 6 indicate the receiver positions with an excellent signal. The yellow squares indicate the receiver positions with a weakened

but strong enough signal. The red squares represent the receiver positions where the link interruption was recorded (RSS < -115). The best signal level was measured on unobstructed routes. The maximum measured range of the link is 360 m in a direction with few obstacles, without brick buildings. Figure 7 shows the maximum measured range of the connection (1944 m) in the case of a clear line of sight in the shown urban environment. The transmitter marked with a blue circle is placed on a hill above the urban area, one meter above the ground. The yellow square marks the position of the receiver where the maximum range of the link (1944 m) with a clear line of sight was measured. Range measurements conducted in the suburban area showed similar results in terms of maximum range.



Figure 7: Link range measurement in an urban area in the case of a clear line of sight

3.1. Experimental results discussion

In order to check the performance of the created LoRa-based remote control link, several experimental measurements were conducted at different locations. Repeated measurements showed the same or very similar results, compared to previously conducted measurements. Based on the experimental measurements, it was determined:

- The created remote control link based on LoRa SX1278 transceivers is very stable and resistant to interference. In case of signal loss (RSS < -115), the link automatically recovers when the position is changed and a stronger signal is obtained. In case of interruption of the transmitter, after it is switched on again, the link is automatically established. Also, in the event of a receiver failure, after turning it on, the link is automatically established. The implemented algorithm for automatic recovery of a broken link allows for maintaining stable remote control within a limited area.
- The connection range in urban environments is significantly dependent on line-of-sight obstacles. In the shown urban environment, the connection was successfully maintained along the routes

without buildings. All obstacles along the line of sight cause a certain signal weakening. Brick buildings introduce more attenuation than trees and prefabricated buildings. The connection is lost after 200 m in case of two or more brick buildings between the transmitter and receiver. The indoor range is 2-3 times better than in the case of a Wi-Fi network. In a brick building with several floors, the connection was maintained even in the most distant rooms. The data transfer speed did not change significantly.

- Most of the experimental measurements were conducted in an urban area in the presence of much stronger radiation at different frequency bands. Although the power of the LoRa transmitter is incomparably lower than the transmission power of most other wireless networks, such as mobile telecommunication and television networks, the established LoRa-based remote control was very stable in a limited area. The obtained experimental results confirm the resistance of the established LoRa remote control link to interference.
- The data rate depends on the amount of data being transferred and the number of control channels. In the case of five-channel control, when five control variables are transmitted, during one second 22 data packets were transmitted. With the same settings, in the case of 10-channel control, 12 data packets were transmitted in one second (Figure 5), without latency. The data packets contained an array of 10 integer control values read from the remote control sensor. In practice, the 10-channel remote control is suitable for most controlled objects and processes.
- Tilting the antenna up to an angle of 30 degrees did not significantly affect the stability of the remote control link and the data rate. The greatest range was achieved when the antennas at both ends were in a vertical position. This means that moving objects such as robots and UAVs can be remotely controlled using LoRa-based remote control.

The obtained experimental results regarding the stability and range of the LoRa-based remote control link are similar to the results presented in the relevant scientific papers [2], [8], [9] and [10]. Improved results in terms of range and link stability could be achieved by using directional antennas with high gains. In such implementations, the radiation pattern of the transmitter antenna must be taken into account, while the receiver antenna must be omnidirectional in case the remotely controlled object is mobile. In the case of remote control of a stationary remote object or process, high-gain directional antennas can be used on both sides. In such implementation, using high gain antennas, communication range could be maximized.

3.2. Further research

The presented experimental results were obtained using the maximum transmission power and default values of LoRa modulation parameters, without data encryption. LoRa modulation technology supports transmission adaptation based on several additional programmable parameters such as spreading factor, channel bandwidth and code rate [11]. There are thousands of different combinations of programmable parameter values. For example, a higher spread factor increases the range, but at the same time decreases the data rate. Higher bandwidth increases the data rate, but decreases the sensitivity, etc. Finding the optimal combination of parameters for an implemented remote control link assumes numerous experiments with different parameter values. It would be interesting to find the best approach to tune the programmable LoRa modulation parameters to achieve optimal remote control performance.

4. CONCLUSIONS

This paper shows how advanced LoRa technology can be used to remotely control objects such as robots and UAVs. Based on the presented experimental test results, which are comparable to the published experimental results, it can be concluded that the remote control link based on the LoRa SX1278 transceiver is suitable for remote control of various remote processes and objects such as robots and UAVs, providing a stable link with acceptable data rate. The range of the LoRa transceiver in case of a clear line of sight is up to 10 km [7]. In urban areas, the range of the LoRa based link depends on the obstacles placed between the transmitter and the receiver. For example, the experimental results have confirmed that two or more brick buildings prevent connection even at a distance of 200 m. By choosing a good location for the transmitter antenna, a longer range is achieved.

The advantages of the presented LoRa-based remote control solutions are:

- Long-range remote control,
- Stable communication link,
- Low price,
- Low power consumption,
- Simple implementation.

The disadvantages of the presented solution are:

- Limited range in urban areas,
- Limited data rate up to 300 kbps.

The LoRa SX1278 module provides a two-way half-duplex connection, so it can be used to establish two-way communication links as well as to network with other LoRa transceivers. The available data transfer rate of the LoRa module is sufficient for remote control of most real objects such as robots and UAVs. The presented findings can be used for further research into the possibilities of LoRa transceivers in the field of long-range remote control.

REFERENCES

- [1] S. Devalal, A. Karthikeyan, "LoRa Technology - An Overview", Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, pp 284-290, 2018
- [2] G. C. Pătru, D. C. Trancă, C. M. Costea, D. Rosner, R. V. Rughiniș, "LoRa based, low power remote monitoring and control solution for Industry 4.0 factories and facilities", 18th RoEduNet Conference: Networking in Education and Research (RoEduNet), Galati, Romania, pp 1-6, 2019
- [3] J. Ru, Z. Dong, Z. Guangyuan, G. Zhiguang, W. Xuelin, S. Anwar, "Application of Remote Wireless Control Technology Based on LoRa System in Intelligent Agricultural Machine", International Conference on Robotics and Automation in Industry (ICRAI), Peshawar, Pakistan, pp 1-4, 2023
- [4] I. Mwammenywa, D. Petrov, P. Holle, U. Hilleringmann, "LoRa Transceiver for Load Monitoring and Control System in Microgrids", International Conference on Engineering and Emerging Technologies (ICEET), Kuala Lumpur, Malaysia, pp 1-5, 2022
- [5] B. S. Kumar, S. Ramalingam, V. Divya, S. Amruthavarshini, S. Dhivyashree, "LoRa - IoT based Industrial Automation Motor Speed Control Monitoring System", International Conference on Intelligent Data Communication Technologies and Internet of Things (IDCIoT), Bengaluru, India, pp 11-15, 2023
- [6] H. Rajab, T. Cinkler, T. Bouguera, "IoT scheduling for higher throughput and lower transmission power", Wireless Netw. 27, 1701–1714, <https://doi.org/10.1007/s11276-020-02307-1>, 2021
- [7] Semtech Corporation, LoRa SX1276/77/78/79, Datasheet, rev. 4, 2015
- [8] M. R. Seye, B. Ngom, B. Gueye, M. Diallo, "A Study of LoRa Coverage: Range Evaluation and Channel Attenuation Model", 1st International Conference on Smart Cities and Communities (SCCIC), Ouagadougou, Burkina Faso, pp. 1-4, 2018
- [9] R. Berto, P. Napoletano, M. Savi, "A LoRa-Based Mesh Network for Peer-to-Peer Long-Range Communication", Sensors, Basel, Switzerland, 2021
- [10] W. D. Paredes, H. Kaushal, I. Vakili, Z. Prodanoff, "LoRa Technology in Flying Ad Hoc Networks: A Survey of Challenges and Open Issues", Sensors, Basel, Switzerland, 2023
- [11] M. C. Bor, U. Roedig, "LoRa Transmission Parameter Selection", 13th International Conference on Distributed Computing in Sensor Systems (DCOSS), Ottawa, Canada, 2017

BIOGRAPHY

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