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ONE SOLUTION OF LOW-COST LORA BASED IOT MODULAR CONTROL DEVICE

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Abstract

This paper aims to improve a low-cost modular control device based on the IoT concept by integrating long-range LoRa communication technology. The LoRa communication technology enables the use of a modular control device in areas without implemented Internet and Wi-Fi infrastructure.

Key words: *LoRa, IoT, modular, control device.*

1. Introduction

The Internet of Things (IoT) is a concept that connects physical devices, objects, and systems to the Internet, allowing them to collect, exchange, and process data without the need for human intervention (Stankovski et al., 2020, 2021; Tarjan et al., 2020; Tegeltija et al., 2022, 2023). The key idea of IoT is to create a network of smart devices that can analyze and modify the collected data to optimize performance, improve efficiency, and provide users with personalized services. This includes many devices, from smartphones, sensors, home appliances, cars, and industrial equipment and infrastructure. IoT devices are equipped with processing units, sensors, actuators, and communication interfaces, which enable mutual communication and interaction with the environment via the Internet. The processor unit manages the operation of the entire IoT device. With the help of sensors, the IoT device becomes aware of its surroundings and collects data. The processing unit processes the data collected from the sensor. Based on the results of e-data processing, the IoT device influences its environment through actuators or

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forwards data to other IoT devices or systems through the communication interface. IoT has wide applications in various sectors, in industrial and non-industrial systems. In households, it enables the development of smart houses where devices such as lights, locks, and thermostats communicate with the user via applications. In agriculture, smart irrigation systems optimize water use based on weather conditions. In industry, IoT helps monitor and maintain equipment in real-time, reducing costs and increasing productivity. For the implementation of the Internet of Things concept to be possible, it is necessary to provide Internet access to every device. This is easily feasible in urban areas with a developed and implemented communication infrastructure such as Wi-Fi networks, mobile phone networks, etc. In some regions, there is no implemented communication infrastructure, or it is of poor quality.

This paper aims to improve a low-cost modular control device based on the IoT concept realized in previous research by integrating long-range LoRa communication technology. This technology enables the use of a modular control device in areas without implemented Internet and Wi-Fi infrastructure.

2. Proposed solution

To realize this paper, a modular control device based on the IoT concept realized in previous research was used (Tegeltija et al., 2023). This modular control device is based on the ESP32 platform (Espressif, 2024). The ESP32 platform provided several advantages. First of all, the developed device was simple. It had a large number of built-in functionalities. It can be easily programmed using the Arduino IDE development environment. Ultimately, the device's price was very low and acceptable to many users. The disadvantage of this device was that the ESP32 platform allowed connecting to the Internet only via a Wi-Fi network. This means that this modular control device requires the existence of a Wi-Fi infrastructure to communicate with other devices and systems. To eliminate this shortcoming and improve the device, the LoRa communication interface was chosen.

3. LoRaWAN: the possibilities of LPWAN

LPWAN (Low-Power Wide-Area Network) is a category of wireless network technologies designed for long-term IoT applications that require low power consumption and the transmission of small amounts of data over long distance (Raza et al., 2017). These technologies allow devices to be connected across wide geographic areas with minimal power requirements. They are ideal for sensors and other IoT devices that run on batteries and communicate intermittently. The application of LPWAN technology is wide and can be found in Smart City Applications, Personal loT Applications, Home Automation & Safety, Smart Grid & Smart Metering, Industrial Assets Monitoring, Logistics, Critical Infrastructure Monitoring, Agriculture and Wildlife Monitoring & Tracking (Raza et al., 2017). The key features of LPWAN are (Tarjan, Tejić, Tegeltija, et al., 2018): low power consumption, long-range (2-20 km) low data transfer rate (in the range of a few kilobits per second), low costs (unlicensed bands). Among the most used LPWAN technologies are (Tarjan, Tejić, Dragičević, et al., 2018): LoRaWAN (Long Range Wide Area Network), Sigfox, NB-IoT (Narrowband IoT).

LoRaWAN is a network architecture that enables IoT devices to connect to the Internet or applications via LoRa infrastructure. The main purpose of this protocol is to allow the long-term operation of battery-powered devices in applications such as smart cities, asset tracking, environmental sensors, and agriculture (Adelantado et al., 2017). LoRaWAN uses a star-topology network in which devices (called nodes or end devices) communicate with gateways (base stations), and these base stations are connected to a central network server. Each LoRaWAN device communicates directly with one or more base stations, depending on the coverage, without the need to interconnect the devices (Loukil et al., 2022).

The components of the system are (Adelantado et al., 2017; LoRa Alliance, 2024):

1. End-devices: These are IoT sensors or devices that communicate via LoRa technology. These devices use LoRa modulation to transmit data to the nearest base station. Their main goal is to periodically send small amounts of data (e.g., information about temperature, location, and water level) to the network. Devices can be static (such as sensors in agriculture) or mobile (such as vehicle tracking systems).
2. Gateways: A LoRaWAN gateway or base station is a device that receives a signal from end devices via a LoRa module and forwards that data via the Internet to a network server. Gateways do not process data, they redirect the incoming signal. One base station can cover many devices and a significant area (up to several kilometers in urban areas and tens of kilometers in rural areas).
3. Network server: After the gateway receives the signal from the end devices, it forwards it to the network server. A network server processes incoming data, manages the network, forwards messages to user applications, and controls device access. It also filters multiple copies of messages from different base stations and performs data decryption.
4. Application server: After processing the data on the network server, it is sent to the application server, which provides an interface to the users for analysis and further use. The application server can be connected to software applications that control devices, perform data analysis, or automate various tasks.

LoRaWAN supports two-way communication, which means that devices can send data to the network (uplink) and receive messages from the network (downlink). This enables functions such as remote software updates, sending commands to devices, or monitoring status.

Key features of LoRaWAN (LoRa Alliance, 2024):

1. Long range: The range depends on the density of obstacles and the environment, but can be up to 5-15 km in rural areas and 2-5 km in urban areas.
2. Low power consumption: It is designed for devices with low power consumption. The devices are mostly in sleep mode and are only activated when they need to send data, allowing the batteries to last for years (often up to 10 years).
3. Use of unlicensed frequency bands: ISM bands are unlicensed and free to use, reducing operational costs. Bands vary by region, so Europe uses the 868 MHz band, while the US uses 915 MHz, and 2.4 GHz is available worldwide.
4. Adaptive Data Rate (ADR): This supports a mechanism known as ADR (Adaptive Data Rate) that automatically adjusts the data rate depending on the quality of the connection between the device and the base station. In this way, an optimal balance between range, connection stability, and energy consumption is achieved.
5. Security: LoRaWAN includes end-to-end data encryption and device authentication. There are two levels of security: network encryption, which protects the integrity and authenticity of messages between the device and the network, and Application encryption, which protects data from unauthorized access to applications.

LoRaWAN defines three classes of devices that have different operating modes to enable a balance between energy efficiency and speed of reaction to downlink messages. Class A devices have the lowest energy consumption. They support two-way communication, but can receive messages only a short time after sending an uplink message. This is the most energy-efficient class. Class B includes devices that periodically open time windows for receiving messages according to a predefined schedule, which enables more frequent downlinks. Class C devices constantly listen for incoming messages, except when sending uplink messages. Class C consumes the most energy, but provides the fastest response.
Examples of LoRaWAN applications are:

- Smart cities: Air quality monitoring, waste management, smart lighting.
- Smart farming: Monitoring soil conditions and automatic irrigation.
- Smart meters: Remote reading of water meters (**Error! Reference source not found.**), electricity meters, gas meters.
- Asset Tracking: Track vehicles, shipments, and other movable assets.

LoRaWAN operates in unlicensed ISM frequency bands (Industrial, scientific, and Medical bands) for which a license is necessary. These are different frequency bands used for wireless communication, and each has specific characteristics and uses in telecommunications (Rappaport, 2001).

ISM bands are frequency bands globally reserved for industrial, scientific, and medical purposes but are widely accepted for wireless communications in other applications as they do not require licensing. This means that any technology or device can use those frequencies without permission or without paying spectrum usage fees (Rappaport, 2001; Tarjan, Tejić, Tegeltija. ISM bands are designed to withstand interference and different applications because they are used for different purposes.

The most commonly used ISM bands include:

- 433 MHz (in some regions)
- 868 MHz (Europe)
- 915 MHz (North America)
- 2.4 GHz (global) – used for Wi-Fi, Bluetooth, and many other wireless standards
- 5.8 GHz (used for certain industrial applications and Wi-Fi).

The advantages of ISM bands are that anyone can use them because they are free and do not require licensing, which reduces development and implementation costs. These bands, such as 2.4 GHz and 868/915 MHz, are available worldwide and are suitable for IoT, home devices, wireless sensors, industrial applications, and more.

The disadvantages of the ISM band are interference and limited range. Because these bands are license-free and open to wide use, interference often occurs, especially in densely populated areas and places with a large number of devices operating in the same bands (e.g., residential Wi-Fi networks). Compared to licensed bands, these bands, especially those at higher frequencies like 2.4 GHz, may have a shorter range and less penetration through obstacles (walls, buildings).

Implemented solution

Communication modules from LilyGO were selected to improve the modular control device. These modules integrate the ESP32 platform and Lora communication transceivers on the same module. Depending on the LoRa frequency band they support, these communication modules come in multiple versions. To implement this solution, we used two versions of LilyGO T3 S3 modules (LilyGO, 2024). One version uses a Semtech SX1276 transceiver for operation on an 868 MHz frequency band. Other version use a Semtech SX1280 transceiver for operation on a 2.4 GHz frequency band. Figure 1 shows a modular control device with an attached LilyGO T3 S3 module with a LoRa communication module operating at 2.4 GHz. LilyGO T3 S3 modules were chosen because they have a very similar footprint to the DOIT ESP32 DevKit V1 used as a control module in the original version of the modular control device. With minor modifications (due to the different arrangement of power supply pins, digital IO pins, and pins for communication via the I2C interface), it is possible to directly install these modules as the central module of a modular control device. The basis of the control software of the central module is identical because the same development environment (Arduino IDE) is used, the only thing that needs to be added is the commands for communication via the LoRa communication interface. All this makes it possible to easily and quickly implement the software in the central module to add the possibility of LoRa communication through the LoRa network. An additional advantage of LilyGO modules is the relatively low price.

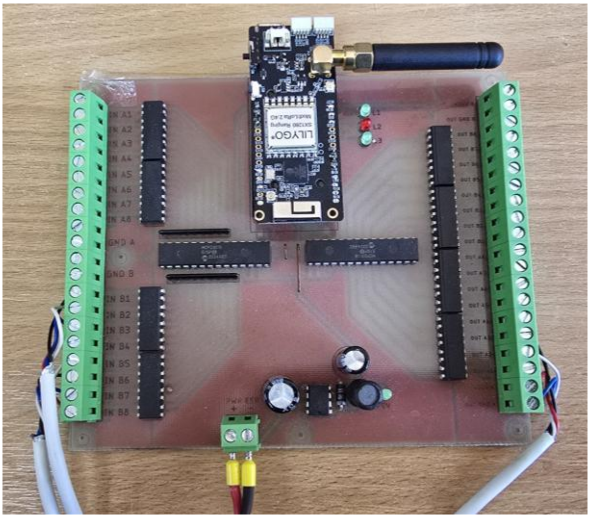

Figure 1: Modular control device with LilyGO T3 S3 SX1280 module

It is planned to use LilyGO T3 S3 LR1121 modules for future work because they have integrated bands of 868/915 MHz and 2.4 GHz on the same module. This would further improve the modular control device because the same communication module is used for the 868/915 MHz and 2.4 GHz bands, which increases flexibility and enables quick and easy adaptation to different LoRa networks in different regions.

4. Conclusion

This paper describes the proposed solution for improving the modular control device based on Internet of Things technology. The improvement has brought the possibility of communication via LoRa networks to the modular control device. Communication modules were selected to enable the improved version of the modular control device to maintain simplicity, speed of implementation, modularity, and relatively low price.

The improved version of the modular control device maintains the basic functionality that the original version had, but communication via the Lora network was added. Initial tests of communication through the Lora network gave very good results. Still, it is necessary to carry out additional research to determine the optimal communication parameters within the LoRa networks in various scenarios. Such scenarios may depend on the user's needs, such as the required range and speed of data transmission and the different environments in which the control devices are placed (urban and rural environments, plain or mountain areas, forests, fields, etc.).

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