Journal of Applied Data Sciences
Vol. 5, No. 3, September 2024, pp. 1258-1271

Development and Research of an Autonomous Device for Sending a Distress Signal Based on a Low-Orbit Satellite Communication System

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(Received: June 6, 2024; Revised: June 22, 2024; Accepted: July 24, 2024; Available online: August 10, 2024)

Abstract

Due to the importance of providing reliable communication for sending distress signals, research on the development of an autonomous device via low-orbit satellites is becoming particularly relevant, offering innovative solutions capable of providing fast and reliable communication in extreme situations. The purpose of this study was to investigate a device capable of operating autonomously in emergency situations and providing fast transmission of a signal about the need for help. The comparative method, statistical method, and analysis were used in the framework of research. The results of the study showed the significant potential of Long-Range Wide Area Networks (LoRaWAN) technology in the field of wireless communication. It provides high stability and noise immunity of data transmission, which makes it an attractive choice for various applications. Due to its high scalability, LoRaWAN is capable of servicing tens and hundreds of thousands of devices, making it an ideal solution for large-scale projects. LoRaWAN can achieve data transmission rates between 0.3 kbps to 50 kbps, with power consumption as low as 1.2 µA in sleep mode and 28 mA in transmit mode, and communication ranges up to 15 km in rural environments. Because of its low power consumption, it is ideal for use in battery-powered devices such as smart and distress sensors. In addition, it was found that the use of EBYTE E32 modules in LoRaWAN devices ensures reliable and efficient data transfer. The study confirms the potential of LoRaWAN technology for developing efficient and reliable wireless communication systems for various Internet of Things applications, ensuring reliable data transmission under various conditions. The results obtained are of great practical importance for the creation and further improvement of autonomous devices for the rapid sending of distress signals, contributing to increased safety and responsiveness to emergency situations.

Keywords: Internet of Things, LoRaWAN, Data Transmission, Power Consumption, Emergencies

1. Introduction

In circumstances where emergencies and disasters become increasingly inevitable and devastating, the need for reliable communications to send distress signals becomes vital. In such critical moments, effective communication can be a key factor that determines the ability to carry out operational rescue measures and the ability to provide assistance to victims. However, the disadvantage lies in the fact that existing means of communication do not provide sufficient reliability and efficiency of transmitting distress signals in the conditions of disasters and emergencies [1]. The difficulty lies in developing an autonomous device that will be able to operate independently of the infrastructure, and provide stable communication in conditions where conventional communication networks may be damaged or disconnected. It is required to create a technology capable of sending distress signals via low-orbit satellites with high speed and reliability, which is a non-trivial task due to limited resources and limitations in the energy consumption of such devices. Research in this area is designed to develop a device for sending distress signals with innovative communication technologies that will significantly improve society's ability to respond to emergencies, the coordination of rescue services and contribute to more effective and prompter assistance to victims [2].

Analysis of Long-Term Evolution (LTE) and 5G capabilities in the study by F. Völk et al. [3] revealed their high bandwidth, low data transmission latency, and improved efficiency of using the frequency spectrum. It is noted that due to the widespread use of LTE mobile networks and the development of 5G technology, these standards can become

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DOI: https://doi.org/10.47738/jads.v5i3.289

 ISSN 2723-6471

an important component in an integrated communication system for a distress signal transmission device. G.N. Mizamova [4] argues that the use of LTE-based mobile networks provides reliable communication for autonomous distress signal transmission devices. These technologies are characterized by wide coverage and high availability, which makes them an effective means of communication in various conditions and places. As a result of the study, it was noted that the LTE standard offers high data transfer rates, improving the capabilities of an autonomous device for communication in emergency situations. According to A. Adamova et al. [5], the Internet of Things (IoT) technology plays a key role in the development of autonomous devices for sending signals. The use of IoT allows collecting and transmitting data from various sensors and devices in real time, which ensures prompt response to emergencies and increases the efficiency of the monitoring and management system [6]. With the ability to remotely monitor and control via the Internet, IoT-based autonomous devices can function in a wide range of scenarios, including environmental monitoring, security monitoring and medical care systems.

S.S. Abdullayev and A.S. Abdullayeva [7] emphasize the importance of using IoT technology for the development of autonomous distress signal transmission devices. IoT technology provides the ability to collect, process and analyses data from various sources, which allows quickly responding to emergencies and preventing potential threats. Due to the possibility of integration with various sensors and devices, autonomous IoT-based devices can monitor the environment, monitor the condition of infrastructure facilities and provide assistance in case of emergencies [8]. Following A. Amenova and K. Chezhimbayeva [9], one of the promising areas for creating such a device for sending signals is the use of Narrowband Internet of Things (NB-IoT) networks. This technology is specifically designed to connect devices to the IoT and has a number of advantages, including low power consumption, long range and high penetration through walls and obstacles. NB-IoT provides stable communication in remote and hard-to-reach locations, which makes it an attractive option for autonomous distress signal transmission devices.

Since the above-mentioned papers did not pay enough attention to a detailed analysis of the possibility of developing a device for sending a distress signal based on innovative communication technologies, the purpose of this study is to create a unique prototype of the device and its comprehensive investigation.

2. Materials and Methods

This study was carried out using such approaches as comparative method, statistical method, and analysis that evaluated the existing technical solutions in the field of autonomous devices for sending distress signals.

The comparative method helped to identify the advantages of the technology in question in creating an autonomous device for transmitting distress signals based on a low-orbit satellite communication system. By carefully evaluating the comparative characteristics with other communication technologies, it was found that the technology in question has a higher communication range, low power consumption, and the ability to operate in various frequency ranges, which makes it a good and promising choice for transmitting distress signals [10]. In addition, a comparison with other wireless networks revealed the advantages of this technology in compatibility with existing networks, high noise immunity, and the ability to service a large number of devices, which makes it ideal for scalable applications [11]. The study analyzed LTE, 5G, IoT, and LoRaWAN communication technologies to determine the best option for autonomous distress signal transmission. Performance indicators like reliability, power consumption, data transfer rate, and communication range were assessed. Scalability potential and compatibility with current infrastructure were also evaluated. IoT and LoRaWAN were praised for low power consumption and long-range communication capabilities, while LTE and 5G were compared for high bandwidth and low latency.

Thus, the comparative method identified the approaches under consideration as optimal technologies for creating autonomous communication devices capable of functioning effectively in emergency situations and providing communication in remote and hard-to-reach places. The statistical method was used to assess the performance of various components and technologies, including communication range, data transfer rate, and power consumption. It also assessed the reliability and stability of system components under different operating conditions [12], [13], [14], [15]. The testing environment involved field experiments in real-world conditions and controlled laboratory settings. A distress signal transmission device was tested in a controlled laboratory setting using a Raspberry Pi Pico microcontroller, LoRaWAN module, and sensors. The device was tested in urban, suburban, and rural environments to simulate real-world emergency scenarios. The device was installed at a fixed location and tested for data transmission, power consumption, battery life, and environmental impact assessment. The device's performance was also evaluated under different weather conditions, including rain and wind, to assess its robustness and reliability. The device enclosure was also tested for water and dust resistance.

The study analyzed the performance and efficiency of various components and technologies in developing an autonomous device for transmitting distress signals. Quantitative data was collected from technical specifications, experimental testing, and real-world usage situations. Key characteristics like power consumption, data transfer speeds, communication range, and signal dependability were monitored. Statistical techniques like regression analysis, variance analysis (ANOVA), and hypothesis testing were used to verify the performance claims of various technologies. This thorough examination ensured that the chosen technology was supported by actual data, fostering confidence in its reliability and effectiveness. The statistical results were crucial for forming conclusions and recommendations, ensuring the reliability and validity of the research results.

The study analyzed communication technologies, comparing them with wireless networks to determine compatibility, noise immunity, and serviceability. It also examined the technical specifications of components like microcontrollers and modules for autonomous communication devices. Factors like operational efficiency, processor speed, memory capacity, power management, and protocol compatibility were considered to develop an autonomous distress signal transmission device. Simulations were conducted to assess the system's functionality in real-world scenarios and its ability to sustain communication in infrastructure-damaged settings. A feasibility study was conducted to evaluate potential solutions and practical implementation issues. The analysis provided a detailed understanding of each technology's characteristics, allowing for optimization of configuration and functionality.

Thus, the combination of various analysis methods provided a more accurate and informative assessment of technologies, which contributed to the successful design and creation of an autonomous device for transmitting distress signals (figure 1).

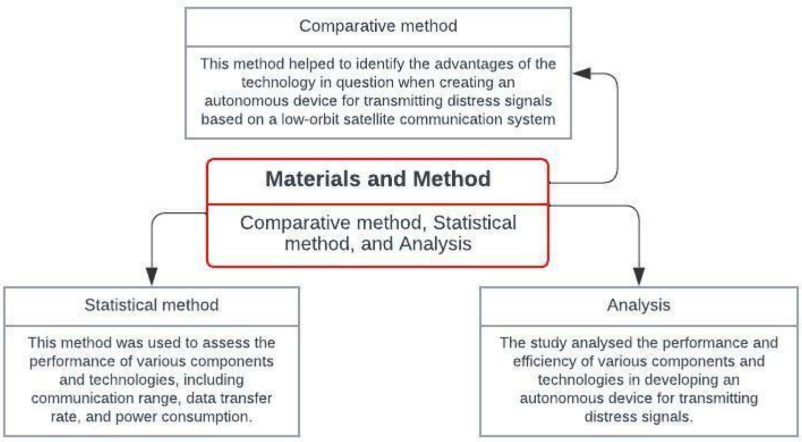

Figure 1. Demonstration of methods and materials

3. Results

The Republic of Kazakhstan is witnessing the rapid development of the LoRaWAN network, which is one of the leading areas of Low Power Wide Area Network technology. This network is used in a variety of applications to transmit small amounts of data over long distances. LoRaWAN is characterized by high efficiency and low energy consumption, which makes it an ideal choice for implementing IoT-related projects in the region. The LoRaWAN system is one of the key infrastructure elements for various IoT projects, due to its ability to provide stable and reliable data transmission even in conditions where other wireless technologies may experience difficulties [16].

Using LoRaWAN for distress signals has several security benefits, including network protection, privacy, tamper resistance, encryption, and authentication. These characteristics are intended to guarantee the security of the data being sent, the protection of the devices and network from unwanted access, and the preservation of the integrity and confidentiality of the distress signals [17]. The safe and dependable use of LoRaWAN technology in emergency communication applications depends on the implementation of certain security measures, which guarantee the unhindered transmission and reception of distress signals.

In Kazakhstan, there is interest from many companies seeking to deploy their own IoT networks based on Long Range (LoRa) technology. The specific feature of LoRaWAN technology is the use of narrowband communication with a channel width of 125 kHz in the frequency range 864-869 MHz's This allows for reliable data transmission over long distances with minimal power consumption. LoRa modulation technology is an innovative approach to data transmission that provides a significantly longer communication range compared to alternative methods. Based on the principle of modulation with Chirp Spread Spectrum, LoRa allows for efficient data transmission over long distances with minimal energy consumption. Additionally, the integrated Forward Error Correction (FEC) increases the reliability of data transmission, which makes this technology an ideal choice for a wide range of applications, including communication systems for sending distress signals based on a low-orbit satellite system [18], [19]. The effective method of forward error correction increases the dependability and effectiveness of data transfer networks. FEC ensures the integrity of the sent information even under difficult circumstances by introducing and using redundant data, enabling receivers to identify and fix problems instantly. Due to this, it is a fundamental part of contemporary communication technologies, where it is imperative to preserve data accuracy and reduce retransmissions.

LoRaWAN optimizes data transmission rates in order to provide long-range, low-power connectivity. The precise data rates that were examined in this investigation varied from 0.3 kbps to 50 kbps. These rates were selected in response to the requirement for long-distance, effective data transfer with low power consumption. The transmission rates were noted: 0.3 kbps (using a spreading factor of 12 and bandwidth of 125 kHz); 0.6 kbps (spreading factor 11, bandwidth 125 kHz); 1.2 kbps (spreading factor 10, bandwidth 125 kHz); 2.4 kbps (spreading factor 9, bandwidth 125 kHz); 4.8 kbps (spreading factor 8, bandwidth 125 kHz); 9.6 kbps (spreading factor 7, bandwidth 125 kHz); 19.2 kbps (spreading factor 7, bandwidth 250 kHz); 50 kbps (using Frequency-Shift Keying, bandwidth 125 kHz).

LoRaWAN's low power consumption makes it ideal for battery-powered devices, which is one of its main benefits. The investigation examined power use in several operating modes: 1.2 µA in the sleep mode; 1.6 mA in idle mode; 28 mA in transmit mode at 14 dBm of transmission power; 10 mA in a receive mode. LoRa technology is a revolutionary data transmission method with high receiver sensitivity and efficient channel bandwidth use. It can demodulate signals with levels 19.5 dB below noise level, a feat that requires higher signal power in frequency manipulation systems. LoRa modulation is flexible and versatile, allowing it to be used in various network architectures and protocols, making it an ideal solution for creating various IoT projects, including grid, star, and point-to-point networks. This makes LoRa an ideal solution for various IoT applications.

LoRaWAN network nodes are highly desirable for IoT applications due to their low power consumption, which can last up to 10 years on conventional AA batteries, making them an ideal choice for devices that require extended operation without the need for power supply replacement [20]. LoRaWAN, despite its low data exchange rate, offers a long communication range, enabling wide coverage in rural and densely built-up areas. Network nodes can provide communication over 15 km in rural areas and 5 km in densely built-up urban areas. The low cost of terminal equipment makes LoRaWAN an affordable technology for various applications, enabling the deployment of large-scale IoT networks with minimal equipment costs, contributing to the development and implementation of new technologies in various industries [21]. To further understand LoRaWAN's performance in various settings, tests were conducted in both urban and rural areas. The following outcomes of the tests were obtained: suburban environment – up to 10 km range (with moderate building density); rural environment – up to 15 km range (with little obstacles); urban environment – up to 5 km range (with high building density and probable interference). These ranges show that LoRaWAN can communicate over great distances, which makes it useful for applications in isolated and difficult-to-reach locations. Chirp Spread Spectrum modulation is used to attain the range, enabling reliable signal transmission even in difficult situations.

ISSN 2723-6471

The LoRa network is known for its flexibility, featuring three classes of devices: Class A, Class B, and Class C. Each class offers different levels of functionality and capabilities, allowing them to be adapted to specific project needs. Table 1 presents these classes, each with its own characteristics and features, allowing users to choose the optimal device based on application conditions and network requirements.

Table 1. Device classification in LoRa

LoRa MAC	MAC options		Class A (basic level)
			Class B (basic level)
			Class C (permanent)
	LoRa modulation	ISM regional range	EU 868
			EU 433
			US 915
			AS 430

Note: MAC – Media Access Control; ISM – Industrial, Scientific, and Medical.

Class "A" is a standard functional format in LoRa technology that defines the basic principles of information transmission. The end device initiates communication by sending small data according to a pre-set schedule to the gateway. After data transfer, the device opens a reception window for a certain time interval, waiting for a response from the server. If no response is received, the device switches to standby mode to minimize power consumption. A second receiving window opens in a coordinated subband with the server, collecting and transmitting data as soon as the device is activated again. Class A networks are widely used in monitoring applications due to their energy efficiency and ease of use. In class "B", a reception window is added, synchronizing the end device's internal time with the network time using a special "beacon" signal from the gateway. This allows the server to start transmitting data at a predetermined time, increasing the efficiency and reliability of information transmission. Class "C" devices in LoRaWAN networks have a long and almost continuous reception window, making them ideal for applications requiring continuous data acquisition. However, they consume the most energy, making them impractical for battery operation. Despite this, they ensure data is received from the network server with minimal delays, making them crucial for tasks like real-time monitoring and management systems. The architecture of LoRaWAN networks is complex and includes several key elements. In the classic LoRaWAN network, four main components can be distinguished: end-nodes, gateways, a Network Server, and an Application Server (figure 2).

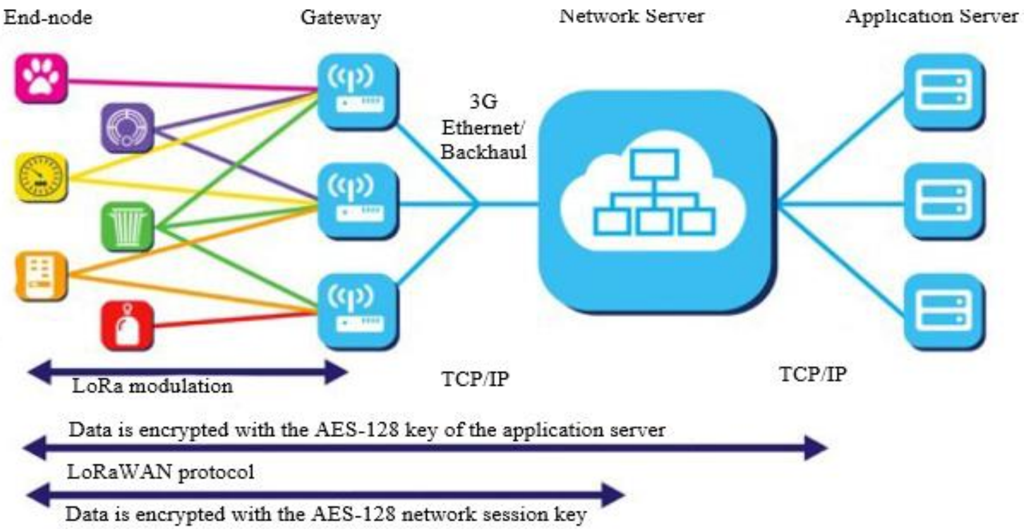

Figure 2. Architecture of the LoRaWAN network

End-node performs important functions in the LoRaWAN network, designed for management, monitoring and measurement. They are usually equipped with a set of different sensors and control elements that allow collecting data from the environment or perform certain tasks. Usually, such nodes are powered by batteries, which ensures their independence from external energy sources [22]. End-nodes regularly transmit their data to the network at specified time intervals, usually in the range from 1 to 5 seconds, then two reception windows open to process responses. At other times, the devices are either in standby mode or in active reception mode, depending on their class. This energy saving strategy reduces energy consumption and extends the battery life of the end nodes.

Gateway/Concentrator LoRa plays a key role in the LoRaWAN network, receiving information through a radio channel and transmitting it to networks that may include channels such as Ethernet. A star topology is being created in the network, in which gateways and end devices interact with each other. In addition, the LoRa gateway is usually equipped with multi-channel transceivers. This provides an extended network coverage area and efficient two-way information transfer between end devices and the server [23]. The Network Server is responsible for managing the LoRaWAN network, including setting a data transfer schedule, and storing and processing incoming data. It is a key element in ensuring the reliability and efficiency of the entire network. The Application Server is designed to remotely monitor the operation of end nodes and collect the necessary data from them. It provides an interface between the LoRaWAN network and applications that use data from the network, which enables effective management and monitoring of various devices and processes.

Raspberry Pi Pico is an open-source microcontroller that can be used to create devices using LoRaWAN technology. It can function as a control module for low-orbit satellite communication systems, collecting and processing data from sensors and transmitting it through the LoRa module on board Pico. Based on the RP2040 microcontroller developed at the Raspberry Pi Foundation (UK), this board has high performance and flexible digital interfaces. The main advantage of the RP2040 is its dual-core Arm Cortex M0+ processor, capable of operating at frequencies up to 133 MHz, which provides high speed and performance. Moreover, the Raspberry Pi Pico has 264 KB of SRAM and 2 MB of internal flash memory, providing enough space for storing data and programs [14]. An autonomous distress signal transmission device's central processing unit (CPU), the Raspberry Pi Pico, gathers data from sensors including accelerometers, temperature sensors, and GPS. Through its interface with the E32-433T33D LoRaWAN module, data packets can be delivered and received via the LoRaWAN protocol across extended distances. The Pico is a great alternative for monitoring environmental conditions and sending distress signals because of its low power consumption and versatile interface choices, which also improve the system's usefulness and stability.

Other important features include the availability of universal serial bus (USB) 1.1 with device and host support, low-power sleep and sleep modes for efficient power management, and support for USB drag-and-drop programming, making development on this board convenient and affordable. In addition, Raspberry Pi Pico has a wide range of interfaces, including 26 multifunctional general-purpose input/output (GPIO) contacts, serial peripheral interface (SPI), inter-integrated circuit (I2C), universal asynchronous receiver-transmitter (UART), analogue-to-digital converter (ADC), controlled pulse width modulation (PWM) channels. Additional features such as an accurate clock, an integrated temperature sensor, and accelerated floating-point libraries make the Raspberry Pi Pico an ideal choice for a wide range of electronics and programming projects [24]. Microcontrollers require GPIO connections for simple hardware component interaction and input/output capabilities. SPI is a synchronous serial communication protocol for short-range communication with sensors and peripherals. I2C is a multi-master, multi-slave, packet-switched, single-ended serial communication bus developed by Philips Semiconductor. UART is an asynchronous hardware protocol for reliable serial communication. Real-world sensor processing uses an ADC for conversion of analogue signals into digital ones. Controlled pulse width modulation regulates power flow and creates analogue signal levels.

Raspberry Pi Pico provides opportunities for connecting peripheral devices due to the presence of 40 pins with a standard 2.54 mm pitch on the sides of the board. Using the Pico with breadboards requires soldering a pin plug to it. However, the focus is on the 26 GPIO pins with additional features. Of these, 3 contacts are capable of receiving analogue signals via a 12-bit ADC, which opens up opportunities for working with analogue sensors and measuring devices. 16 contacts allow generating analogue signals in the form of PWM signals (figure 3).

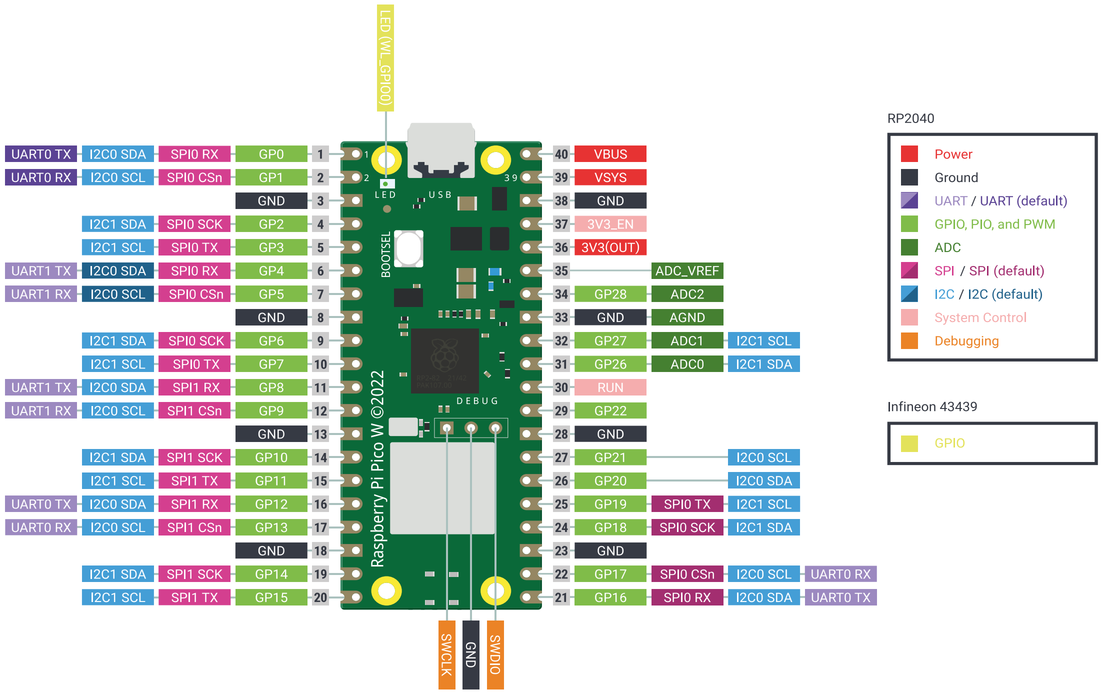

Figure 3. Raspberry Pi Pico Microcontroller

Source: [14].

In addition, 12 pins enable peripheral devices to get direct memory access without the direct involvement of the processor, which increases the efficiency of data processing. UART, SPI, and I2C hardware interfaces are available for connecting modules, which provides flexibility in choosing external devices. Programmed input/output (PIO) allows adapting the Raspberry Pi Pico to work with various hardware interfaces through any of the 26 GPIO pins, expanding its functionality and usability. However, it is worth remembering that Raspberry Pi Pico is compatible only with modules operating at a logical voltage of 3.3 V, and connecting peripherals with a voltage of 5 V can damage the device [25]. This controller provides extensive programming capabilities, supporting the C/C++ software development kit or the official MicroPython port. In the future, it is planned to add Raspberry Pi Pico support to the Arduino integrated development environment, which will greatly simplify the development process for a wide range of developers. The platform is powered via a micro-USB connector, the recommended supply voltage is 1.8-5.5 V, providing flexibility in choosing a power source.

Unlike single-board computers, Raspberry Pi Pico does not run an operating system, which allows you to fully focus resources on running a single programme. This feature is especially valuable for projects requiring high efficiency and minimal energy consumption. A unique feature of Raspberry Pi Pico – PIO, which allows implementing arbitrary hardware interfaces, such as the secure digital card bus or video graphics array. Optimized floating-point calculations help to cope with complex tasks and projects, providing the necessary power and memory to solve various tasks. Due to its low power consumption and compact size, Raspberry Pi Pico is ideal for use in standalone devices where reliable and long-term battery operation is required. However, the ability to programme in Python using MicroPython makes the development of applications for working with LoRaWAN on Raspberry Pi Pico more accessible and convenient for a wide range of developers.

MicroPython is a Python 3 programming language adapted for embedded systems like Raspberry Pi Pico, allowing developers to use familiar Python syntax for microcontroller programming. It features an interactive read-eval-print loop prompt, enabling immediate command execution and code experimentation via a USB serial port. Additionally, it has a built-in file system for managing files and storing data directly on the device. The MicroPython port for Raspberry Pi Pico includes special modules designed to interact with the microcontroller hardware, which provides access to low-level functions and capabilities of the chip for developers [26], [27]. When developing MicroPython software for Raspberry Pi Pico or Pico W, there is no direct way to determine which device it is intended for by looking at the hardware. However, it can be found out indirectly by paying attention to the included networking features in a particular version of MicroPython firmware (figure 4).

```
import network
if hasattr(network, "WLAN"):
   # the board has WLAN capabilities
```

Figure 4. Assessment of WLAN capabilities via MicroPython network functions

The code snippet in Figure 3 checks if a board has WLAN capabilities using the hasattr function, which is crucial for assembling self-sufficient devices for emergency communication. This ensures the device's effectiveness in delivering distress signals and helps identify potential hardware limitations early in the development process. Ensuring the microcontroller supports WLAN is a prerequisite for implementing wireless communication protocols like LoRaWAN, allowing for timely adjustments. An additional way to determine whether the MicroPython firmware was compiled specifically for Raspberry Pi Pico or Pico W is to check the firmware version itself. This can be done using the sys module in the Python programming language (figure 5).

```
>>> import sys
>>> sys.implementation
(name='micropython', version=(1, 19, 1), _machine='Raspberry Pi Pico W with RP2040', _mpy=4102)
```

Figure 5. Use of the sys module to identify MicroPython implementation on Raspberry Pi Pico W

The code snippet in Figure 4 showcases the Raspberry Pi Pico W's MicroPython implementation, importing the sys module and accessing the implementation property to display machine name, version, and other information. This code is crucial for developers to understand and optimize performance, especially in emergency communication applications. The Raspberry Pi Pico W's wireless capabilities and compatibility with MicroPython make it an ideal choice for distress signal devices. Understanding the software environment and hardware details helps in debugging and optimizing the code. The E32-433T33D module, based on the SEMTECH SX1276 RF chip, is a UART module that finds wide application in LoRaWAN technology and the development of devices with innovative communication technologies (figure 6, figure 7). It has a transparent data transmission mode and operates in the frequency range of 410~441 MHz (default 433MHz), which makes it compatible with LoRa's extended spectrum technology. This module ensures reliable, efficient data transmission over long distances with low power consumption, crucial for autonomous device development in limited energy and communication infrastructure conditions. Within the framework of LoRaWAN, this module can be used to establish communication between nodes and gateways, providing data transmission in the global IoT network for monitoring and managing various devices and systems [13].

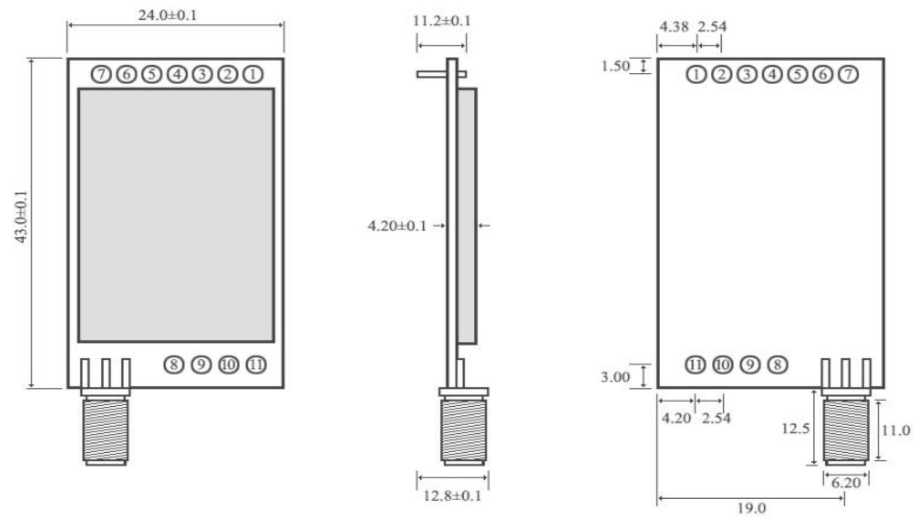

Figure 6. Circuit diagram and dimensions of E32-433T33D module

Source: [13].

Figure 7. EBYTE E32-433T33D LoRa transceiver module with SMA antenna connector

Source: [13].

The E32-433T33D module, manufactured by EBYTE, is a crucial component in autonomous distress signal transmission devices. Its dimensions are 24 mm in width, 43 mm in height, and 11.2 mm in depth, making it easy to fit within the enclosure and connect to the Raspberry Pi Pico microcontroller. The detailed diagram on figure 5 and figure 6 help in planning device assembly and troubleshooting issues, avoiding design conflicts and streamlining the integration process. The module operates in the 433 MHz frequency band, allowing for extended communication ranges in remote environments. It features an SMA connector for an external antenna and pin headers for interfacing with microcontrollers. Compliant with FCC and CE standards, it is suitable for various regions and offers features like data encryption and low power consumption, making it an excellent choice for emergency communication applications.

The SX1278 module, equipped with LoRaTM technology, is an advanced solution for ensuring high communication range and confidentiality of data transmission. The E32-433T30D model based on this chip is in stable mass production and is widely used in various fields in practice. It has data encryption and compression functions, which ensures a high level of confidentiality and transmission efficiency. Data transmitted over the air is characterized by randomness, and the default data transfer rate is 2.4 kbit/s. Encryption and decryption algorithms make data interception meaningless, ensuring the reliability and security of transmission. In addition, data compression reduces transmission time and reduces interference, which, in turn, increases the overall reliability of data transmission [28].

This module is a popular solution for various applications due to its wide communication distance of up to 8 km, maximum transmission power of 1 W, and multi-level software control. It supports the ISM 433MHz global unlicensed band, ensuring compatibility across different countries. The module also uses new generation LoRa technology, providing high data transfer efficiency with low power consumption, making it ideal for battery applications. Its multi-level software control allows for accurate data configuration. The standard industrial-grade design with support for operating temperatures from -40°C to 85°C guarantees reliability and stable operation in various operating conditions. The availability of the sub-miniature version A access point makes the module convenient for additional development and integration into various systems and devices [29]. In general, the main advantages of LoRaWAN wireless networks are determined by several factors, including the use of LoRa broadband modulation and operation in unlicensed frequency ranges. These networks also have a number of advantages including compatibility with existing networks and wireless data transfer technologies which makes LoRaWAN a convenient choice for integration into an existing infrastructure, which makes it easy to implement new applications and expand network functionality. High noise immunity of LoRaWAN networks ensures reliable data transmission even in conditions of severe interference, which makes them suitable for use in various environments, including urban areas with high levels of interference. Another advantage is the ability to service tens and hundreds of thousands of devices which makes LoRaWAN an ideal solution for scalable IoT applications such as smart city systems, lighting management and environmental monitoring. Lastly, the large coverage area and low power consumption of terminal devices make LoRaWAN networks effective for use in applications where data transmission over long distances with minimal energy consumption is required, for example, in monitoring and management systems for remote facilities.

LTE and 5G networks offer wide coverage in urban and suburban areas due to their dense infrastructure, outperforming LoRaWAN in terms of data throughput and latency. They are ideal for bandwidth-intensive applications like gaming, autonomous cars, and video streaming, while LoRaWAN is suitable for low-bandwidth applications like sensor data transfer. However, due to higher power consumption, they are less suitable for battery-operated devices. LoRaWAN networks are ideal for wide-area IoT deployments in rural and underdeveloped regions, but require more investment and maintenance. LTE and 5G offer enhanced security features, robust authentication, and increased dependability for mission-critical applications. The anticipated cost of the autonomous distress signal transmission device, which consists of an E32-433T33D LoRa module, sensors, power supply units, and a Raspberry Pi Pico microprocessor, is between $40 and $65. The gadget will cost between $50,000 and $100,000 to manufacture and install, and maintenance expenses will cover items including battery replacement, hardware repair, and software upgrades. Potential savings from the gadget include lower search and rescue expenses, increased emergency response efficiency, and possibly even saved lives.

Thus, LoRa technology, combined with Raspberry Pi Pico and MicroPython, provides unique opportunities for creating autonomous communication devices capable of transmitting distress signals based on a low-orbit satellite communication system. The Raspberry Pi Pico microcontroller provides flexible digital interfaces and hardware management, while MicroPython provides a convenient software environment for code development and debugging. Ebyte E32 modules, in turn, extend the communication range and ensure reliable data transmission in various conditions. All these components together form a powerful toolkit for creating effective and reliable communication systems capable of responding to emergencies and ensuring safety in various use cases.

4. Discussion

The development and research of innovative communication technologies are crucial for the safety and rapid emergency response of disasters. These devices are essential for transmitting distress signals in remote and hard-to-reach areas, where conventional communication may be disrupted or inaccessible. The study of autonomous devices ensures operational communication in situations where conventional channels may be damaged or disabled. Low-orbit satellite communication systems enable these devices to transmit distress signals even in extreme conditions, increasing the chances of a quick and effective response to emergencies. The development of such devices also contributes to the improvement of disaster warning systems and rescue operations coordination. By deploying these devices strategically, the ability to respond to various emergencies can be significantly improved. Thus, research is of fundamental importance for ensuring the safety and protection of life and property in emergency situations.

According to O. Kodheli et al. [30], one of the promising technologies for creating devices for sending distress signals is the integration of modern communication and data transmission methods, such as satellite communications. Microsatellite systems are crucial for providing wide coverage and reliable communication in remote areas, especially for distress signal transmission. These systems can be designed to meet specific requirements for extreme conditions. Both studies emphasize the importance of using advanced communication technologies for distress signal transmission. Satellite communications offer wide coverage and reliability in remote areas, while LoRa technology offers high communication range and low power consumption, making it attractive for distress signal transmission systems. Both studies emphasize the need to choose optimal technologies like LoRa and satellite communications for reliable communication in extreme conditions.

S.K. Rathor and D. Saxena [31] argue that the development of smart energy management systems and battery backup power supplies can be an effective technology. The study suggests that integrating innovative energy saving methods and alternative energy sources can enhance the autonomy and reliability of autonomous devices, even with limited energy resources. It also emphasizes the importance of efficient energy management systems and backup power sources in enhancing device autonomy. Both studies highlight the need for sustainable energy solutions. The study by the researchers focuses on the development of systems capable of ensuring the smooth operation of devices with limited energy resources, which emphasizes the importance of increasing energy efficiency. The results of this study also reflect this trend, pointing to the use of LoRa technology, which is known for its low energy consumption. Both studies confirm that the integration of innovative methods of energy saving and the use of alternative energy sources is an important area for the development of autonomous devices and contributes to their reliability and durability.

The development of algorithms for processing and analyzing data on board devices, as noted by G. Giuffrida et al. [32], is an important area for improving distress signaling systems. This aspect allows for more efficient data analysis and real-time operational decision-making, which significantly improves the capabilities of autonomous devices in emergency situations. Notably, the integration of such algorithms into LoRa technology may present some challenges due to the bandwidth and power consumption limitations of this technology. Although LoRa provides low power consumption and communication range, it can limit the amount of data transmitted and the transfer rate. The integration of complex data processing algorithms such as machine learning and artificial intelligence can require large amounts of data and computing resources, which is important to consider when using LoRa technology.

As a result of the study by T.Y. Cheng et al. [33], is argued that a promising technology for creating autonomous devices is the integration of neural networks into communication systems. It is noted that neural network technologies, especially in the field of data processing and decision-making, can significantly improve the process of analyzing and classifying information received from sensors in a device for sending a distress signal. Researchers have found that integrating neural networks into communication systems can improve the efficiency of autonomous devices and data analysis and classification. This could enhance the effectiveness of LoRa technology in emergency situations. However, the integration of such algorithms into LoRa technology remains open. As technology advances, specialized hardware and software solutions may emerge, allowing for the integration of neural network algorithms into LoRa systems, thereby improving the system's ability to adapt and provide accurate and timely data for rescue operations.

According to E. Hajlaoui et al. [34], an additional technology that can complement the system of an autonomous device for sending a distress signal is the use of a communication system based on mobile networks. Mobile networks like 4G and 5G offer high data transfer speeds and reliable communication, making them ideal for remote distress signaling systems. However, integrating these networks into a comprehensive system can improve device reliability and efficiency. While both studies offer different technological solutions for disaster communication, LoRa technology offers unique advantages, such as longer communication range and low power consumption, making it ideal for devices with limited power supply. Despite these advantages, LoRa remains a more cost-effective and efficient solution for disaster communication.

In general, research in this area is of key importance to ensure communication in remote and hard-to-reach areas in case of emergencies. They can help improve the effectiveness of rescue operations by providing fast and reliable information transmission, which contributes to a faster response to emergencies. For the purpose of creating autonomous distress signal transmission devices, LoRaWAN and the Raspberry Pi Pico have many advantages, but they also have limitations. LoRaWAN's performance can be impacted by scalability problems, environmental effects, and the requirement for careful network management. Similarly, while developing applications, Raspberry Pi Pico's restricted processing power, lack of built-in connection, and environmental durability need to be taken into account.

5. Conclusion

As a result of research, the application of LoRa technology to create an autonomous distress signal transmission device has been investigated. It was revealed that LoRa technology has a number of advantages, such as high communication range, low power consumption and the ability to operate in various frequency ranges, which makes it the optimal choice for transmitting distress signals.

LoRaWAN networks based on LoRa broadband modulation and operation in unlicensed frequency bands provide advantages in compatibility with existing networks and technologies, including high noise immunity. These networks are capable of servicing tens and hundreds of thousands of devices, ideally suited for scalable IoT applications. Due to the large coverage area and low power consumption, LoRaWAN is effective for long-distance data transmission with minimal energy consumption, which is useful in monitoring and management systems for remote facilities. The Raspberry Pi Pico microcontroller was considered, which provides a flexible and powerful platform for developing embedded systems, and the MicroPython programming language makes the software development process more convenient and accessible. It was noted that Raspberry Pi Pico offers a rich selection of peripheral interfaces and capabilities such as GPIO, SPI, I2C, which provides a wide range of options for connecting and interacting with various devices and sensors. Its small size and low power consumption make it an ideal choice for embedded systems, especially in the IoT field. Ebyte E32 modules complement this system by providing additional communication range and reliable data transmission. Together, these components provide a complete solution for the creation of autonomous communication devices that can effectively operate in emergencies and provide communication in remote and inaccessible locations.

Further areas of research should include the development of more efficient energy management methods in LoRaWAN devices, which will help extend their service life and improve the overall network efficiency. It is also recommended to investigate new methods for securing data transmission in LoRaWAN considering various cybersecurity threats and risks. Such research will help make LoRaWAN technology even more reliable, safe, and energy efficient, which, in turn, stimulates its wider implementation in various areas of innovative IoT solutions.

6. Declarations

6.1. Author Contributions

Conceptualization: N.O., S.Z., K.C., Y.Z., and N.N.; Methodology: N.O., S.Z., K.C., Y.Z., and N.N.; Software: N.O.; Validation: N.O. and S.Z.; Formal Analysis: N.O., S.Z., K.C., Y.Z., and N.N.; Investigation: N.O.; Resources: K.C.; Data Curation: S.Z.; Writing Original Draft Preparation: N.O., S.Z., K.C., Y.Z., and N.N.; Writing Review and Editing: N.O., S.Z., K.C., Y.Z., and N.N.; Visualization: N.O.; All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP15473717).

6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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