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ANALYSIS OF POSSIBILITIES TO USE NEURAL NETWORK FOR REMOTE CONTROL OF ELECTRONIC DEVICES

Об'єктом дослідження в роботі є системи дистанційного керування електронними апаратами. Існують дротові та бездротові засоби реалізації дистанційного каналу зв'язку між підлеглим та керуючим пристроями. Аналіз існуючих засобів створення каналу зв'язку виявив низьке значення співвідношення гнучкості системи та швидкості передачі даних в середині створеної мережі. Однією з причин низького співвідношення є використання у складі системи модулів зі значним значенням мінімального часу роботи. Такими модулями є модулі фільтрації та декодування отриманого сигналу на боці приймача, кодування та модулювання на боці передавача. Заміна цих модулів на один зі значно меншими показниками затраченого часу суттєво покращить значення співвідношення гнучкості системи та швидкості передачі даних. Можливість для створення модулю, що буде мати необхідні властивості затрачуваного на роботу часу, надає нейрона мережа.

Отримана під час проведення дослідження модель системи дистанційного керування має ряд переваг, зокрема, наявність у складі нейронної мережі дозволяє зменшувати затрачуваний час та підвищити точність роботи системи протягом всього часу роботи системи. Це досягається завдяки здатності нейронної мережі до самонавчання без втручання людини та її можливості аналізувати будь-які вхідні сигнали з різним значенням фонового шуму. Ці властивості дозволяють провести заміну елементів, що не дозволяють підвищити швидкість обміну на елементи нейронної мережі, які будуть виконувати ті самі функції з більшою швидкістю, надійністю та точністю.

Отримані в ході дослідження данні доводять доцільність інтеграції елементів нейронної мережі до складу систем дистанційного керування електронними апаратами. Також запропоновано можливі місця інтеграції нейронної мережі до складу системи дистанційного керування електронною апаратурою, які дозволять підвищити стабільність, точність та швидкість системи.

Ключові слова: *дистанційне керування, нейронна мережа, фізичні інтерфейси передачі інформації, бездротова комунікація.*

1. Introduction

As of today, remote control of various electronic devices is an integral part of any system, despite its direction and scope of activity.

Usually, remote control (RC) of electronic devices is used in cases when contact control over the state of the device is impossible due to possible health risks or the inability to reach the control object.

With the emergence of a large number of personal electronic equipment, in which the possibility of accessing the Internet is realized, the spread of the concept of the Internet of Things (IoT) and cloud technologies, remote control began to receive wider adoption. The creation of new opportunities for remote control and the simplification of existing means of remote control are associated with many indicators, including indicators for:
- security;
- environmental friendliness;
- energy efficiency;
- integration of people with special needs;
- economic justification;
- reliability and maintainability;
- technical support;
- modernization;
- optimization;
- security.

Considering the constantly growing number of new electronic equipment and protocols for its control, the question arises of supplementing the existing methods of remote control with new or improving existing methods. This issue is particularly acute when using wireless communication interfaces between electronic devices. This is due to the high degree of integration of wireless networks in both daily life and in highly specialized areas.

As a result, there is a need to develop new approaches to the use of remote control.

Therefore, it is relevant to analyze the existing means of creating a remote control in order to find the most vulnerable places.

2. The object of research and its technological audit

The object of research in the work is the systems of remote control of electronic devices. Existing systems are created on the basis of both wired and wireless data transfer interfaces, all of which have their own advantages and disadvantages.

One of the most problematic areas of the existing implementation of remote control channels is the low value of the ratio between the properties of the system. These parameters are system flexibility, information transfer speed within the network, as well as system mobility and security [1].

One of the reasons for the low ratio is the use of modules as part of a system with a significant minimum operating time. Such modules are modules for filtering and decoding the received signal on the receiver side, encoding and modulation on the transmitter side. Replacing these modules with one with significantly less time spent significantly improves the ratio of system flexibility and data transfer rate. The ability to create a module that will have the necessary properties of time spent on work, provides a neural network.

3. The aim and objectives of research

The aim of research is searching for possible places for the integration of existing RC models with a neural network.

To achieve this aim it is necessary to solve the following objectives:

1. To make an analysis of modern methods of creating a RC channel.
2. To make an analysis of the capabilities of neural networks.
3. To analyze the RC system, including a neural network.

4. Research of existing solutions of the problem

The main problems of modern means of implementing a communication channel for remote transmission of information are:

a) security of the communication channel and timely detection of intrusions into the created channel;

b) creation of opportunities for management on the basis of various platforms (PCs, mobile platforms, web technologies);

c) speed of information transfer through the created communication channel;

d) ability to quickly switch between different modes of operation;

e) possibility of contactless input.

To solve the problem indicated in paragraph «a», there are a large number of solutions [2, 3], in particular, the use of neural networks and measurements of the signal transit time. Also, the gray relational analysis approach (GRA) is used to ensure the protection of transmitted information and the implementation of a fast connection between devices [4]. This approach can significantly improve the accuracy by introducing into the system abstractions based on information from the transmitter on the receiver. The possibility of improving existing methods of intrusion detection using neural networks [5, 6] ensures fast and reliable operation in real time. The use of neural networks for detecting intrusions into a communication channel allows improving the learning speed of a neuro-fuzzy network, improving the accuracy and speed of intrusion detection in radio networks, and also applying a network for fuzzy network activity [1, 5].

Existing wire tools for creating a communication channel, for example, an optical cable, have high rates of speed, reliability and resistance to foreign intrusion [5, 7]. Using fiber allows to create a reliable connection with high bandwidth [8]. However, along with increasing the stability and speed of such a communication channel, the flexibility of the system and its modularity will decrease.

An integral part of modern electronic devices is the ability to control their state through various platforms. There are a large number of solutions for electronic devices of various kinds [5]. The most common platforms are: network (web), mobile and desktop. The use of various platforms increases the flexibility of the system, provides new opportunities for integration and simplifies management processes.

The use of the IoT approach is particularly acute in raising the issue of «a-e» points. To compensate for the lost flexibility in the composition of RC systems add switches modes [9]. This solution allows to increase the flexibility and modularity of the system due to the rapid switching between the involved parts. The question of contactless input of information (point «e») is becoming increasingly frequent. Modern technologies can significantly simplify the process of entering information into a computer [10]. Along with simplifying the process of entering information, the accuracy of the entered data is improved. Examples of new information entry tools are: neural interfaces, full or partial virtual reality, voice control, etc.

Thus, the results of literary analysis allow to conclude that the problem of finding RC modules with the most time spent working is important.

5. Methods of research

Modern means of organizing RCs have different structures, but still have the same structural units. The relationship between them and the influence of each of the parts on the system as a whole can be depicted by the theory of automatic control (TAC). Each system contains:

– control object (CO) – a technical device or technological process, the change in the values of which must be satisfactory from the users;
– controlled device (CD) – the device, based on the control target and the actual change in the input signal, generates a control signal that should help achieve the goal [11].

The main criteria for any system are:

– stability (property of the system to return to a steady state after it has been removed from this state by any disturbance);
– accuracy (characterized by the error of the system in steady-state modes).

Typical schemes of interaction between the structural elements of the RC system are shown in Fig. 1.

The system shown in Fig. 1, *a*, are: closed, linear and stationary. A feature of the system is the presence of feedback after the filter. This helps to quickly adapt to changes in the input signal. The transfer function of this system will be:

$$W = \frac{W_{if} \cdot W_r \cdot W_d \cdot W_{cd}}{1 - W_{if} \cdot W_{cm}}, \quad (1)$$

where W_{if} – input filter transfer function; W_r – receiver transfer function; W_d – decoder transfer function; W_{cd} – controlled device transfer function; W_{cm} – correction module transfer function.

The system shown in Fig. 1, *b*, are: open, linear but not stationary. A feature of the system is the presence of a control action, the value of which can vary independently of the system. The transfer function of this system will be:

$$W = W_{if} \cdot W_r \cdot W_d \cdot W_{cd}, \quad (2)$$

where W_{if} – input filter transfer function; W_r – receiver transfer function; W_d – decoder transfer function; W_{cd} – controlled device transfer function.

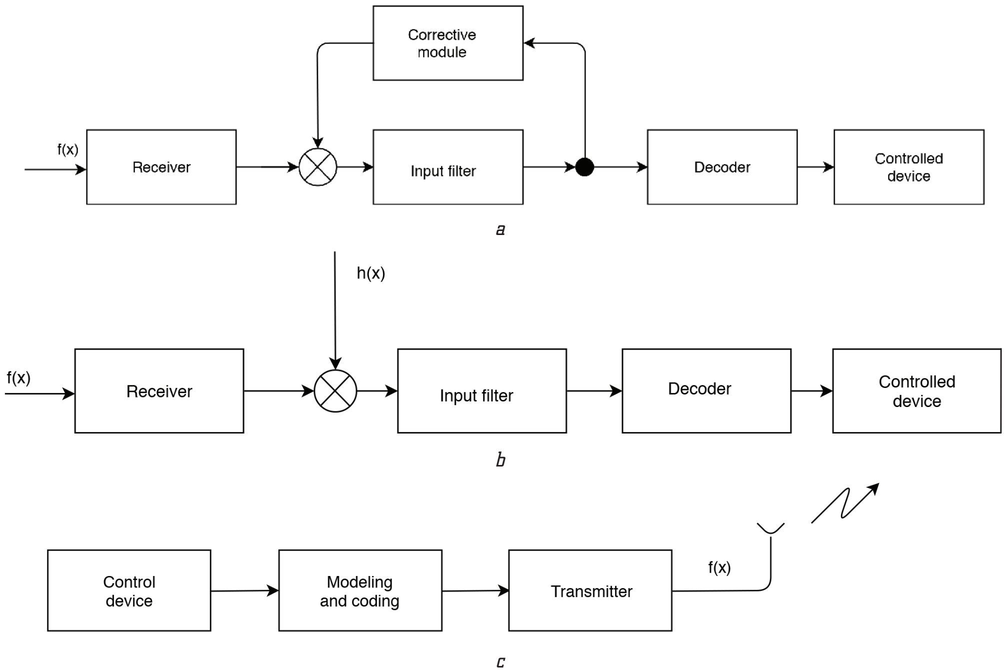

Fig. 1. Typical patterns of interaction between the structural elements of the remote control system: *a* – block diagram of the receiver with a corrective feedback link; *b* – block diagram of a receiver with a control action; *c* – block diagram of the transmitter

The system shown in Fig. 1, *c*, are: open, linear and stationary. The transfer function of this system will be:

$$W = W_{cd} \cdot W_{mc} \cdot W_t, \quad (3)$$

where W_{cd} – control device transfer function; W_{mc} – modulation and coding transfer function; W_t – transmitter transfer function.

To improve the stability and accuracy of the receiver and transmitter systems, let's add a neural network to the composition of both systems. Given the result of the analysis of existing methods of implementing remote control, it is possible to determine the places where neural network integration will lead to the greatest impact on the system. Such places are: the filter of the input signal of the receiver, the processor of the filtered input signal of the receiver and the element of formation of the output signal of the transmitter. The resulting interaction patterns are shown in Fig. 2.

The system shown in Fig. 2, *a*, are: open, linear but not stationary. The transfer function of this system will be:

$$W = W_r \cdot W_{nn} \cdot W_{cd}, \quad (4)$$

where W_r – receiver transfer function; W_{nn} – neural network transfer function; W_{cd} – controlled device transfer function.

As can be seen in Fig. 6, when integrated into the neural network receiver, it replaces the filtering system and the decoder. This simplifies the overall transfer function of the receiver system, increases stability and accuracy by replacing two interconnected modules with one independent one. Thus, it is possible to increase the quality of RC communication with the missing losses in processing time of the received signal.

The system shown in Fig. 2, *b*, are: open, linear and stationary. The transfer function of this system will be:

$$W = W_{nn} \cdot W_{mc} \cdot W_t, \quad (5)$$

where W_{nn} – neural network transfer function; W_{mc} – modulation and coding transfer function; W_t – transmitter transfer function.

The use of a neural network in the transmitter provides the possibility of generating a control signal with increased accuracy rates due to the ability of the neural network to self-learning, which leads to automatic correction of the source data.

Thus, the integration of the neural network into the RC system improves such system parameters as: accuracy, stability, speed of work. Also, the use of a neural network makes the RC system adaptive – it becomes possible to automatically configure the system when the input parameters change.

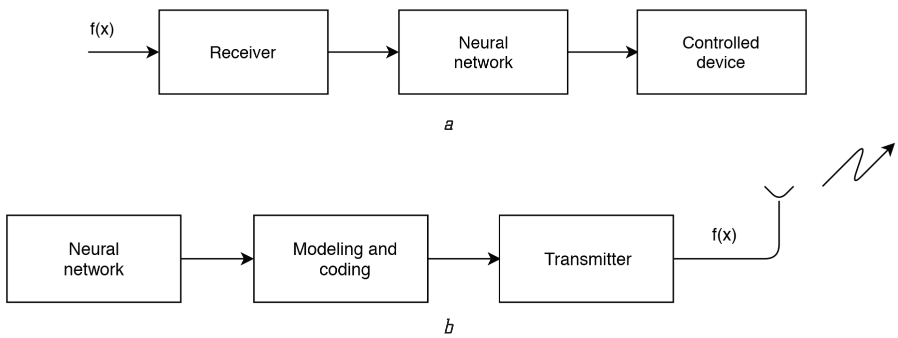

Fig. 2. Diagrams of interaction between structural elements of a remote control system using a neural network: *a* – receiver block diagram; *b* – transmitter block diagram

6. Research results

The analysis of the capabilities of existing remote control tools, as well as the possibilities of introducing a neural network, is carried out on the basis of a three-wheeled operation.

Based on this work, both wired and wireless physical interfaces are analyzed to implement remote control. The interfaces are shown in Fig. 3

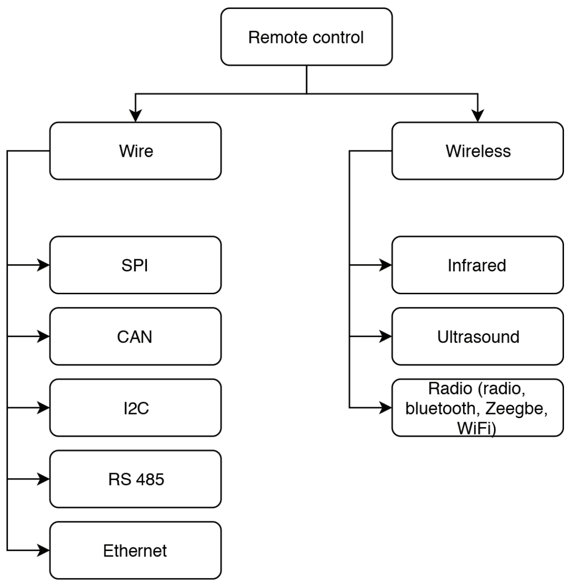

Fig. 3. Considered physical remote control organization interfaces

6.1. Analysis of wired interfaces for the implementation of a remote communication channel. Let's analyze the specified wired remote control implementation interfaces in order to identify their advantages and disadvantages.

SPI (Serial Peripheral Interface) – a serial peripheral interface that uses a synchronous bus to transmit information [12]. The bus includes the following transmission lines: MOSI (master out slave input), MISO (master input slave out), CS (chip select) and CLK (clock). This information transfer interface uses three common for all subordinates, lines (MOSI, MISO, CLK) and one special line (CS) to determine the required subordinate. During the transmission of information to the CLK line, a generated clock pulse is applied. After that, data is fed to the information transmission line. In the case when the CS line is set to logic zero (low impedance) – the signal will be processed, in the case of a logical unit (high impedance) – the signal will be ignored. Each subordinate needs its own CS, which is why the general formula for calculating the number of lines involved is as follows:

$$Lines = 3 + N, \quad (6)$$

where N – the number of subordinates.

Based on the foregoing, it can be concluded that the advantages of the SPI interface is the high speed of information transfer, the synchronism of the transfer process. In turn, the disadvantages are the large number of involved lines.

CAN (Controller Area Network) – an industrial information transfer interface that uses a differential pair for transmission. A feature of this interface is that it is sequential, broadcast and batch.

This means that information is transmitted in packets of a certain length and configuration to all devices simultaneously.

Thus, the decision to process the received packet is performed at the receiver, in contrast to the SPI interface, where the master is responsible for this. Also significant difference of this interface is that the design features impose restrictions on the speed of information transfer. According to the ISO 11898 standard, the maximum length of the line is: 40 m for a speed of 1 Mbit/s, 100 m for a speed of 500 kbit/s, 500 m for a speed of 125 kbit/s, 5000 m for a speed of 10 kbit/s.

This means that a significant disadvantage of this interface is limiting the speed of information transfer and the length of the line. In turn, the advantages of the interface are: high noise immunity, arbitrage access to the network without loss of bandwidth and reliable control of transmission and reception errors.

I2C (Inter-Integrated Circuit) – a sequential asymmetric data transmission bus. Data is transmitted using two lines – the data line and the clock pulse line. In the process of transferring information, there are two sides – the master and the slave.

There can be up to 127 devices on a single bus. Transmission/reception of signals is carried out by pressing the line to 0 in the unit line is established itself, due to the pull-up resistors (usually 10 kΩ). The larger the resistor, the longer the line is restored in the unit and the stronger the front of the pulses, which means the transfer rate drops. That is why the transfer rate in I2C is much lower than in SPI [13].

The advantages of this interface are:

– a small number of conductors for connecting multiple devices;
– possibility of simultaneous operation of several leading (master) devices connected to one I2C bus;
– built-in I2C chip filter suppresses surges, ensuring data integrity.

The disadvantages are: limitations on the capacity of the line (400 pF), the difficulty of using for a large number of possible situations on the bus.

RS 485 – a physical layer standard. The interface protocol provides for two data transfer modes: synchronous and asynchronous, as well as two methods for controlling data exchange: hardware and software. Each mode can work with any control method.

For data transmission over the RS-485 interface, the NRZ code is used, it is not self-synchronizing, therefore the start and stop bits are used for synchronization, which allow to select the bit sequence and synchronize the receiver with the transmitter.

The advantages of the protocol are: exchange rate and reliable control of transmission and reception errors.

Summarizing the considered wire interfaces for the RC implementation, it is possible to say that the wire interfaces have a fairly high transmission speed, reliable error control, line protection from interference and a sufficiently large transmission distance without loss. But the main disadvantage is the use of wires to create a connection. The use of wires is a disadvantage because they make it difficult to create a connection between electronic devices by creating the conditions for the use of wires.

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6.2. Analysis of wireless interfaces for implementation of remote communication channel. Let's conduct analysis of the specified wireless interfaces for the implementation of the RC in order to identify their advantages and disadvantages. To implement wireless control interfaces, let's use electromagnetic waves of varying modulation and frequency, which allows for the use of almost the entire range of electromagnetic waves. The structure of the typical radiocommunication system is shown in Fig. 4 [1].

Based on the principle of wireless communication, the difference between the use of ultrasonic (US) range and infrared (IR) lies in the design features of the transmitter and signal receiver, the properties of the wave of the selected range. Also, the use of these electromagnetic wave bands sets the maximum distance for use and the transmission conditions. Thus, the use of IR radiation requires the absence of other sources of radiation to simplify the filtering mechanism and extract the useful signal. An example of using IR radiation for control is the remote control (up to 20 m), the laser tag system (up to 500 m). The main problem with this interface is the wide infrared spectrum of sunlight. To filter it, as a rule, a modulated signal is used at frequencies of 56 kHz, 36 kHz, 38 kHz, and 40 kHz. This solution allows the use of the infrared range to transmit signals in sunny weather, but sets limits on the maximum distance, significantly depends on the design of the emitter. A significant advantage of the IR transmission channel is insensitivity to electromagnetic interference, which allows the use of this channel in factories and other places with a high level of electromagnetic interference.

Examples of the use of ultrasound for the RC implementation can serve as various consoles, switches and the like.

A significant advantage of the ultrasound is that the radiation source may not use electrical energy, significantly increases the battery life. In such devices, mechanical elements are used to generate ultrasonic waves, and the signal is encoded by modeling it. The choice of the desired modulation occurs by pressing a button on the remote. In turn, the use of such consoles places restrictions on the possibility of reprogramming such consoles due to the use of mechanical filters.

The most common interface for implementing a RC wireless is a radio channel. The range of frequencies involved in radio broadcasts, divided between technologies such as:

– radio communication;
– Bluetooth;
– Wi-Fi;
– Zeegbe.

The largest frequency range is occupied by the radio channel [14]. This wireless interface is most common. It uses a frequency range from 150 kHz (long waves) to 300 GHz (hyper high frequencies). Due to such a wide range of frequencies, radio communication is used in almost all existing areas as an interface for creating a wireless connection between control and controlled devices. The advantages of this interface are the simplicity of the design of receiving and transmitting devices, relatively simple methods for modulating signals (amplitude, frequency, phase). The main problem of transmitting information via radio is radio and electromagnetic interference. Filters of various designs are used to solve this problem. In some cases, filters are involved can be 2nd, 3rd and higher orders.

Technologies such as: Bluetooth, Wi-Fi and Zeegbe is a branch from radio transmission, through the use of specific frequency bands, the use of specific modulations, signal strength and protocols for transmitting information. So, Bluetooth technology uses ISM (Industry, Science and Medicine) – a range for transmitting information. This range is 2.402–2.48 GHz [15]. The technology uses frequent changes in the working frequency (spread-spectrum frequency hopping). This transmission method consists of dividing the spectrum into 79 subchannels and changing the working subchannel every 62 ms.

A feature of the interface is its relatively small distance and the ability to independently switch between frequencies within the established network to ensure signal stability. This interface can be used at a distance of up to 200 m (Bluetooth 5.0) with a maximum speed of 6.25 Mb/s. A special feature of Bluetooth is the low signal power.

Wi-Fi – a flexible interface for wireless information transmission, operating in the range from 2.402 GHz to 5 GHz. The maximum data transfer rate using this interface is 6.77 Gbit/s [16, 17]. Based on the fact that the range of used frequency technologies Wi-Fi and Bluetooth are the same, there is a common drawback for these technologies – the creation of obstacles while working simultaneously. The result of these obstacles is poor signal quality in both interfaces.

The advantage of the technology is the ability to create a network of many devices located at distances from 150 to more than 15.000 m. The distance depends on the conditions of use, physical obstacles to the signal path and the capabilities of the receiving and transmitting antennas that are part of those involved.

The network has high reliability and speed of information transfer, especially at short distances.

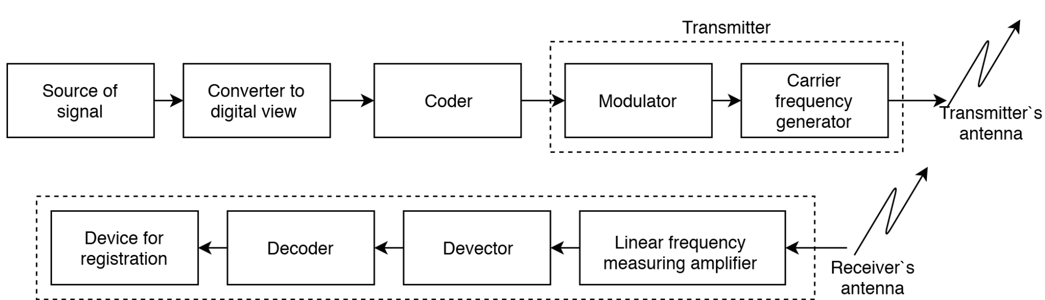

Fig. 4. Structure of a typical radio communication system

Zeegbe – a type of industrial wireless network for transmitting information. It is based on a general-purpose standard using low-power IEEE 802.15.4 radio communication, which allows to customize the floor of a radio signal using various protocols [18]. The main features of the Zeegbe technology are: energy saving, maintaining the network topology of various types of construction, self-healing in the mesh topology with relay and message routing [19, 20].

An example of a network built on the basis of technology Zeegbe is shown in Fig. 5.

Through the use of the principle of mesh and detached nodes, this technology allows to cover large areas. To transmit information in the created network, short packets are used that are transmitted between network nodes at speeds up to 1 Mbit/s.

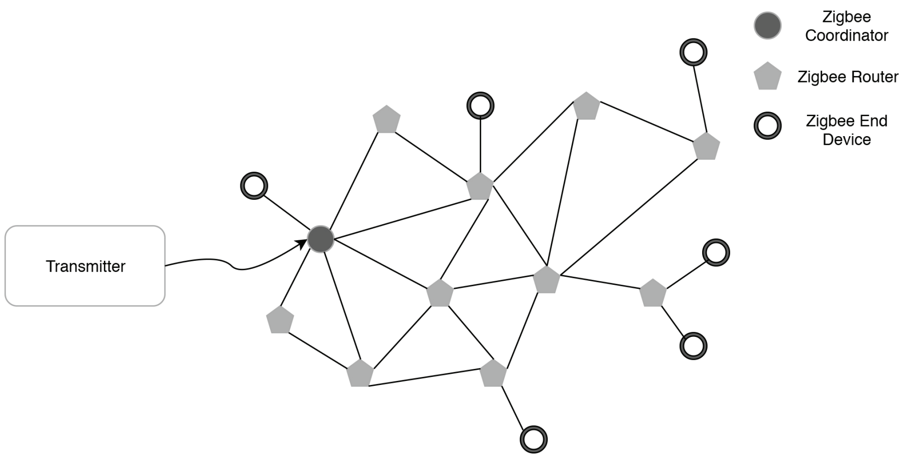

Fig. 5. Example of Zeegbe Network

Thus, the advantages of this technology are: low energy consumption, connection stability due to the use of a mesh, large area of signal coverage, cryptographic protection of all data, low cost, high connection creation speed (30 ms).

In turn, the disadvantages of this technology are: the complex structure of the network for the large number of involved devices, low bandwidth compared with Bluetooth and Wi-Fi.

For all wireless data transmission technology, the following is characteristic [21–23]:

– wide bandwidth. Signals and frequencies used in satellite systems make it possible to transmit not only voice information, but also packet data at a relatively high speed;

– ability to determine the location (coordinates) of consumers;

– low probability of data transmission error. The digital data transmission used in wireless systems uses efficient error detection and correction algorithms;

– sustainable costs. The cost of data transmission over a single connection usually does not depend on the distance between the transmitting and receiving earth stations. In addition, wireless systems are usually broadcast and the cost of transmission remains unchanged with an increase in the number of receiving subscribers.

However, it is necessary to note a number of limitations specific to wireless data transmission technologies:

– the need to protect against unauthorized access to information. The broadcast nature of data transmission allows any ground station tuned to the appropriate frequency to receive broadcast information. Signal encryption is often very complex, which ensures their reliable protection against unauthorized access;

– extremely weak signal that reaches the ground station (due to large distances and limited transmitter power) often requires the use of complex coding and processing methods;

– size of ground stations is usually larger than the size of similar stations in other communication systems (for example, satellite phone and a regular cell phone). This is due to the complexity of the equipment and the need to use relatively large antennas of ground stations;

– significant delay. Long distances from the ground station to the satellite lead to signal propagation delays that reach a quarter-second.

Based on the analysis of wireless tools for the RC implementation, the following general advantages can be identified as:

– fast modernization of the existing network;

– covering a large area signal;

– low power consumption;

– availability of the use of sleep mode for energy saving.

The main disadvantages of wireless tools for the RC implementation are:

– signal obstacles due to the inability to control the transmission medium;

– the possibility of intervening in the created network with a third-party device.

6.3. Analysis of the possibility of using neural networks as part of remote control. A neural network is a huge distributed parallel processor consisting of elementary information processing units that accumulate experimental knowledge and provide them for further processing [24]. The artificial neural network is similar to the natural one in two ways:

– knowledge comes to the neural network from the environment and is used in the learning process;

– to accumulate knowledge, connections between neurons, called synoptic weights, are used. In general, a neural network is a machine that simulates how a brain processes a particular task. The learning process builds in a certain order the synoptic weights of the neural network to provide the necessary structure of neuron interconnections. Changing the synoptic scales is a traditional method of setting up neural networks.

The properties of neural networks make it possible to solve complex problems that today are considered difficult to solve. However, in practice, during autonomous operation, neural networks cannot provide ready-made solutions. They need to be integrated into complex systems [24]. An example of the structure of a neural network with one hidden layer is shown in Fig. 6 [25].

The use of neural networks provides the following useful properties of systems:

1. *Nonlinearity.* Artificial neurons can be linear and nonlinear. The nonlinearity of the neural network is specific because it is distributed throughout the network. It is an

extremely important property, especially if the physical mechanism itself, which is responsible for the formation of the input signal, is also non-linear.

2. *Reflection of input information in the output*. One of the popular learning paradigms is learning with a teacher. This refers to a change in synoptic weights based on a set of labeled learning examples. Each example consists of an input signal and the corresponding desired product. An example is randomly selected, and the neural network modifies the synoptic weights to minimize discrepancies between the desired output and those generated by the network according to a given statistical criterion.

3. *Adaptability*. Neural networks have the ability to adapt their synoptic weights to environmental changes.

4. *Fault tolerance*. When a failure occurs in the involved electronic equipment, the performance of neural networks drops slightly.

5. *Scalability*. The parallel structure of neural networks potentially accelerates the solution of some tasks and ensures the scalability of neural networks within the framework of VLSI (Very Large Scale Integrated) technology. One of the advantages of this technology is the ability to present fairly complex behavior using a hierarchical structure.

6. *Homogeneity of analysis and design*. Neural networks are universal information processing mechanism. This means that the same design solution of a neural network can be used in many subject areas [24].

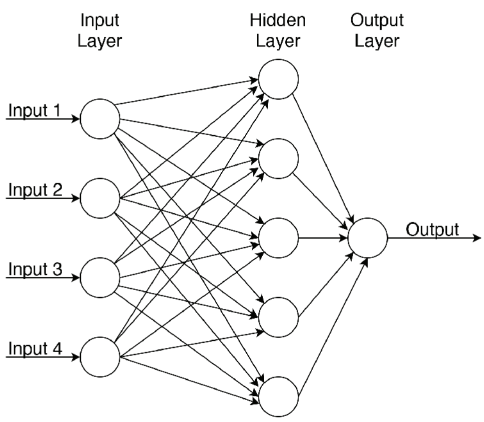

Fig. 6. An example of the relationship of elements of an artificial neural network

The neural network is based on the following principle. The input signal is fed to the input perceptrons (neurons of an artificial neural network), the result of their work is transmitted to the inner layers of the network, where the main part of the information analysis takes place. The number of inner layers may vary depending on the complexity of the task. The results of the inner layers are transmitted to the outer output layer as a result of the network. An example of the relationship between elements of the neural network is shown in Fig. 4.

Based on the principles of neural network training, cited in the sources [18–20], it is possible to determine the following advantages of the neural network:

– ability to adapt to the input information;
– ability to self-test results and adjust existing dependencies automatically;
– ability to learn from data with different values of the quality of input information;
– ability to use an existing network to solve problems of a different nature;
– presence of a large number of ready-made networks of various types and the possibility of creating your own type of network when the need arises.

The disadvantages of neural networks are:

– need for large amounts of data for initial network training;
– impossibility of a quick restructuring of the network due to the complexity of the structure;
– resource consumption;
– inability to quickly adapt the network for other tasks.

During the study, an analysis of the existing methods of remote control implementation was made and potential sites for integration with the neural network were identified. These places were:

– filter input signal receiver;
– handler of the filtered input signal of the receiver;
– element of formation of the transmitter output signal.

Analysis of the capabilities of neural networks allowed to establish methods that can potentially increase such indicators of the RC system, such as:

– accuracy;
– speed of signal processing;
– reliability;
– stability.

The analysis of RC systems without neural networks and with them was carried out from the theory of automatic control. Models of systems, with which help the analysis was carried out, is represented in Fig. 2, 3, respectively.

7. SWOT analysis of research results

Strengths. The use of neural networks as part of a remote control model can significantly improve the quality of filtering as the source and input signals, and also allows to simultaneously expand and simplify methods for generating signals to commands.

Weaknesses. Based on the obtained values, it should be noted that the use of a neural network as part of a remote control model requires a significant amount of system resources, namely, RAM. The degree of nesting of the neural network, which can be used and the processing time of the information by the neural network, significantly depends on this indicator. This means that insufficient RAM can level the complexity of the neural structure and the number of perceptrons.

Opportunities. The use of neural networks is justified on the side of the main network element, or on the side of the receiver in case of availability of the necessary resources for processing. The use of neural networks in RC allows to solve complex problems many times faster.

Threats. The use of neural networks requires the availability of free computing resources, which will lead to higher prices for the RC system as a whole.

8. Conclusions

1. The analysis of modern methods of channel implementation for remote control is carried out. Within the framework of this task, the existing interfaces for the organization of reliable connections between electronic devices and the existing approaches to the organization of communication

between various devices are analyzed. The result of this task is identification of the advantages and disadvantages of the existing methods for the RC implementation. The disadvantages of the RC implementation with the use of wired interfaces are the low value of the flexibility of the system and the vulnerability of the transmission channel to mechanical damage. In turn, the advantages are isolation of the transmission channel from the external environment and high speed information transfer.

2. The analysis of the possibilities of neural networks is carried out. As a result, the features of neural networks are highlighted, which will improve the quality of the remote control system, namely:

– ability to self-learning;

– ability to use as input data with a significant value of noise.

3. A remote control model is created, which includes a neural network. The resulting model is analyzed by the theory of automatic control. According to the results of the analysis, it can be seen that the transfer function of the overall system has become much simpler. This suggests an increase in the stability of the system as a whole due to a decrease in destabilizing effects.

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