Optoelectronic Cyber-Physical System of Monitoring of Nature Protection Areas

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Abstract

The basic principles of construction of modern cyber-physical systems (CPSs) are stated. The priority areas of CPS application are emphasized for computerized monitoring of protected areas, space satellite telecommunications systems, monitoring the spread of global changes in forests, as well as their impact on the growth of carbon dioxide in the atmosphere and global warming on the planet. Characteristics of nature protection objects are systematized as non-stationary and quasi-stationary sources of information. Prospects for the use of open optical data transmission channels with binary-manipulated signals, which provide effective protection of wireless laser channels from the effects of intense multiplicative atmospheric interference (rain, snow, dust, fog) are substantiated. High-performance microelectronic components and structures of specialized processors for the formation and digital processing of binary-manipulated optical signals are proposed. New high-performance structures for streamlining priority information flows based on deep parallelization of information flows, reduction of hardware complexity and maximum speed increase have been developed.

Keywords

Cyber-physical systems, background monitoring, nature protection areas, manipulated optical signals, special processors, streamlining data flows.

1. Introduction

An important functional environment of modern society is information telecommunications systems and IT technologies for the formation, transmission, processing, storage and use of data.

In publications [1,2] the fundamental concept of multilayer CPS platform construction and structure is outlined. The basic principles of CPS implementation are also formulated by J.Wan and his colleagues [3]. The main functions of CPS and their application are described in publications [1,4], which reflects the interaction of the information system with the physical world, methods of collecting, transforming, encrypting and compact data storage.

Decision-making based on pattern recognition is a key issue in the development of theory and principles for the implementation of multilayer and multilevel real-time systems. Especially informational and integral compatibility of these CPS components allows to significantly increase the efficiency of online and offline systems.

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Nowadays, there are a significant number of real-time systems for industrial enterprises. At the same time, background monitoring systems for nature protection areas (NPA) in Ukraine are used very rarely. This situation does not allow the widespread use of existing CPS based on wired and wireless electromagnetic signals, which, as many studies have shown, adversely affect plants, insects and leads to a violation of the regenerative properties of the forest [5-7]. This outlines the high level of improving CPS feasibility and their components based on optoelectronics and wireless communication channels based on manipulated signals.

CPS information sources are:

- analog and digital data at the output of sensors, ADC source codes;
- digital data at the output of encoders, encryption and information protection codes;
- output data of special processors and microcontrollers;
- modulated and manipulated signals of data transmission systems;
- physical and logical data of databases and knowledge bases;
- alphanumeric data and graphic information of 1D, 2D and 3D images.

The above defines the conceptual characteristics of the development and large-scale implementation of CPS in solving problems of information support of nature protection areas.

An important nature protection area in the region of the Ukrainian Carpathians is the Pre-Carpathian oil and gas fields.

Industrial installations of the oil and gas industry are widespread in large areas of Ukraine, so they can significantly affect the ecology of such regions.

Analysis of the geography of the oil and gas province of the Carpathian region of Ukraine [7] shows that throughout its territory there is a significant difference in altitude in the northern direction, accompanied by runoff of many rivers, directly in a large number of geographically distributed oil. This oil and gas province is geographically located in the Carpathians, which contains a significant number of rivers. Therefore, a significant geological and negative ecological impact on environmental protection of this area.

It should be noted that in this region of the Carpathians in the basin of Bystrytsia-Nadvirnyanska river is the territory of the nature reserve "Gorgany" [8].

"Gorgany" Nature Reserve is one of the clusters of the transboundary UNESCO heritage site "Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe". Its territory has the status of la Strict Nature Reserve, provides for the actual preservation and further development of beech and cedar virgin forests.

In Germany, the following nature protection areas have the following status: Iasmuud National Park, Southeast Rugen Biosphere, virgin forests on Bornholm, Schorfheide-Horin Biosphere Reserve, Cedynski Park, Naturpark Uskermaikische Seen, Felgberger Seenlands chaft.

Gorgany Nature Reserve belongs to the strict nature reserves, which is the only standard of human inviolability in the central region of the Ukrainian Carpathians [8]. The German University for Sustainable Development (Eberswalde) is a partner in creating a monitoring system for the Gorgany Nature Reserve.

In Fig. 1 shows a map of the heights of the Gorgany Nature Reserve [8].

The territory of the reserve is characterized by the presence of significant heights 716-1754 м. above sea level with the dominant alpine ridge Dovbushansky and mountain Dovbushanka height 1754 m above sea level.

The described natural protection area in the Carpathian region is not equipped with appropriate information support and real-time monitoring systems in terms of the introduction of CPS technology. This is due to the special characteristics of natural protection area as sources of information. Thus, the analysis of system and information characteristics of such objects is an urgent problem. The solution of which will allow to successfully propose and implement in practice the relevant conceptual principles of CPS construction. Such important principles are the use of state-of-the-art components in the CPS structure, which include: microelectronic remote-controlled sensors; ADC; encoders; special processors; telecommunication tools of data transmission; technologies for monitoring, displaying and compact storage of large data sets.

Figure 1: Map of heights for the territory of the nature reserve "Gorgany"

2. Natural protection areas as sources of information

The task of background monitoring is to obtain information about the state and functioning of geosystems and their constituent components. The essence of monitoring is to observe the environment in space and time, assess the actual situation and predict changes in the future. Objects of monitoring as sources of information are geological environment, atmospheric air, surface and groundwater, soil and vegetation, flora, fauna, natural and anthropogenic impacts on them.

Defining the tasks and objects of background monitoring of the geosystem allows us to establish that according to information analysis and theory of information sources such objects are characterized by quasi-stationary and non-stationary probabilistic properties. Therefore, in the information flows processing generated by such objects, it is necessary to mathematically apply powerful research methods based on the theoretical foundations of systems analysis, synthesis, modelling, generalization, transients under the influence of perturbations, pattern recognition and others.

The Field-Map functions proposed in [8] allow solving a number of tasks in the process of conducting the following monitoring works:

1. climatic, stable meteorological phenomena, observation of the local climate; atmospheric phenomena, precipitation, snow cover, air temperature, wind directions and speed, natural phenomena;
2. water monitoring: surface and groundwater;
3. monitoring of flora and vegetation: natural and anthropogenic impacts, periodicity of monitoring, permanent observation points networks, accounting areas, profiles and transects;
4. study of valuable relict plant communities;
5. forest monitoring;
6. fauna monitoring;
7. landscape monitoring;
8. radio ecological monitoring.

Information arrays of measurements in each quarter of the observed natural protection areas are characterized by a certain diversity of data, so they are combined into clusters.

An example of successful application of the CPS monitoring system in natural protection areas is the system developed by a group of Czech scientists [9]. This system is implemented on the basis of unmanned aerial vehicles (UAVs), which consist of mechanical, electronic and software modules.

The electronic module of the UAV contains [9]: computer for control and storage of data from spectral cameras, LAN GigE interface, industrial computer AAEON - UP Squared UPS-APLC2-A10-0232 is equipped with SSD (mSATA interface) and has a pair of ports 1Gb, Windows OS. This device has three camcorders: hyperspectral camera (Photonfocus MV1-D2048x1088-HS02-96-G2), SWIR camera (Photonfocus MV3-D640I-M01-144-G2-12) and thermal camera (Workswell WIRIS 2 gen). The registration of images is carried out at a certain point with the appropriate overlap from the GPS values, based on the flight distance of the UAV.

It is advisable to use open atmospheric optical channels based on manipulated signals [8] in the absence of cellular coverage, as well as in the conditions of the territories which have the legal status of absolute inviolability (for example “Gorgany” Nature Reserve).

The implementation of telecommunication systems on the territory of natural protection areas is the use of opto-electronic tools based on atmospheric optical channels and fiber-optic communication lines. Optical communication channels are characterized by the absence of generation of electromagnetic radiation into the environment, as well as insensitive to strong atmospheric and electromagnetic influences in the landscape of high mountain areas.

An important source of information on meteorological impact on the natural protection area site is precipitation monitoring (rain and snow). It should be noted that rainfall monitoring is carried out by stationary meteorological stations in standard defined geographical areas. At the same time, measuring the height of snow cover in the winter, especially in protected areas, is practically carried out by operators of route surveyors, according to existing technology [8].

To carry out background monitoring of the height of snow cover in protected areas, the European standard recommends the following technical devices:

1. Electronic GPS radio navigation device.
2. GIS Field-Map.
3. Hammerhead field computer.
4. Laser rangefinder-protractor ForestPro (LaserTech).
5. Electronic complex with Mapstar angle gauge.
6. GPS receiver (SXBlue).
7. Fork for measuring tree diameters (Hadlof).
8. Quadcopter (DJA Phantom 4Pro).
9. Photo trap (GSM Ultra-2G).
10. Instruments and equipment for observations: compass, compass, altimeter, aneroid, fork, tape measure (20 and 50 m.), Age drill, Bitterlich full meter, protractor, magnifier, shovel, ax, dust, field diaries.

The following devices are used for measuring the height of the snow cover: calibrated metrologically certified snow gauge rails: M-103; M-103M; RCC-1.2; PSS-1.8 with the division price 1 cm. and rounding to the nearest whole; snow gauge weight VS-43; portable metal rail M-46; the snow gauge folded M-78.

Snow removal on the field route is carried out once every 10 days [8], and on the forest route once every 5 days. Snow photography is performed by 1-3 routes within a radius of 5 km, from the post and not closer than 0.5 km. from the post. The length of the route is 500 m. with registration every 10m.

The technology of snow cover height monitoring that was described involves the participation of a human operator in the winter and in mountainous conditions. It is extremely time-consuming and information inefficient when the height of the snow cover can vary within 0.5-3 m.

The above information on the observations of these objects as sources of information determines the extremely high relevance of design and development of appropriate structural CPS solutions that able to work reliably in the field in the temperature range -40 - +60 ^{0}C and 100% humidity. Given that the number of sensors in natural protection areas can be hundreds and thousands, their cost should be as low as possible and renewable.

3. CPS architectures for monitoring of natural protection areas based on binary and differentially manipulated optical signals

Legal restrictions on the use of information systems with electromagnetic radiation in the protected areas of the strict reference regime are presented in [8] paper, which include, for example, the “Gorgany” Nature Reserve. Since microelectronic components of such systems must work reliably in field conditions of a wide range of temperatures (-40 - +80 ^{0}C), 100% humidity and high-lightning effects of lightning, it is more appropriate in such protected areas to use laser systems based on atmospheric open optical channels [7,10-14].

The team of authors [8,15-17] proposed a number of new solutions for the creation of information tools designed for background monitoring of flora and fauna of protected areas. It is presented 2D CPS architecture based on a ring-star topology in Fig. 2.

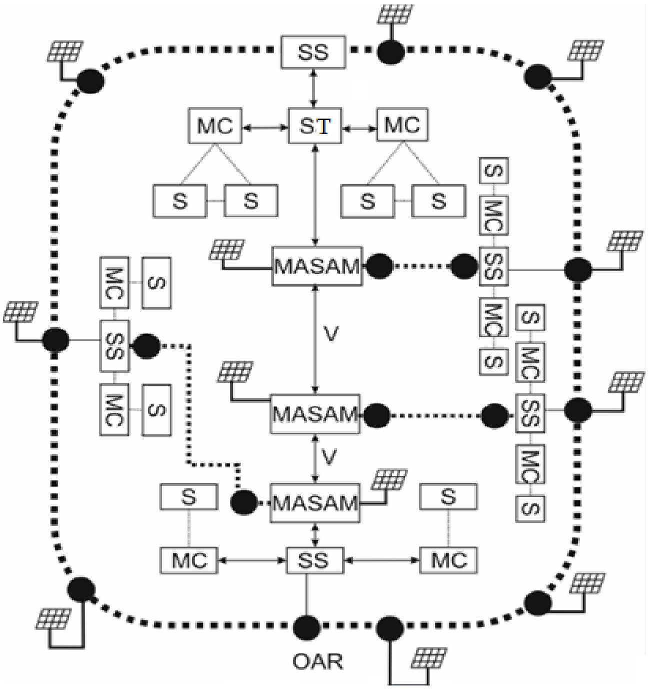

Figure 2: Architecture of computerized background ecosystem monitoring system

The presented architecture is organized on the basis of fiber-optic and open atmospheric communication lines. It contains: ST - subscriber station of the operator of the permanent observation point (POP); MC - microcontroller; S - sensor; V - fiber-optic communication line; MASAM - multiport associative shared access memory; SS - system server; OAR optical active repeaters; ▦ - solar power panel.

In the process of designing microelectronic and optoelectronic equipment, the functional and hardware redundancy of such architecture of the monitoring system was revealed. This is due to functional redundancy structurally complex MASAM [18].

The architecture of such a system is proposed in [16] work. Simpler communication stations (Fig. 3) are used. They are based on binary-manipulated optical signals with ordering of priority-defined bit-oriented streams.

This structure of the multilevel optical star-ring sensor network contains [16]: 1 - system server, 2 - communication stations, 3 - subscriber stations, 4 - monitoring objects, 5 - atmospheric optical telecommunication lines. Each ST is equipped with a renewable power supply, which is not shown in Figure 3. It should be noted that the information links between stations in Fig. 3 can be carried out not only at right angles.

Components of this CPS architecture are sensor networks telecommunications connected to the subscriber stations (AS) of permanent observation points (POP). Open atmospheric channels based on binary-manipulated optical signals were used [8,19].

Atmospheric optical channels are based on the proposed method of wireless transmission and receiving of information. Signals are manipulated by two signal signs "1" and "0" of amplitude for one optical signal source with a laser of a given frequency. Then such a message is received by receiver with registration of corresponding bits "1" and "0" (Fig. 4).

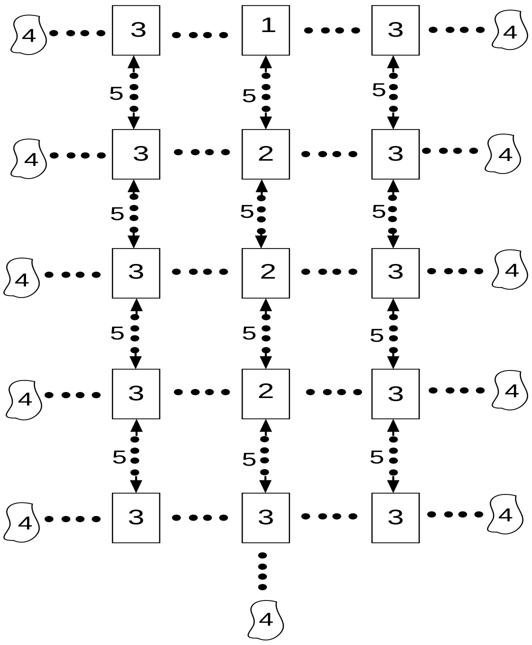

Figure 3: The structure of a multilevel star-ring sensor network

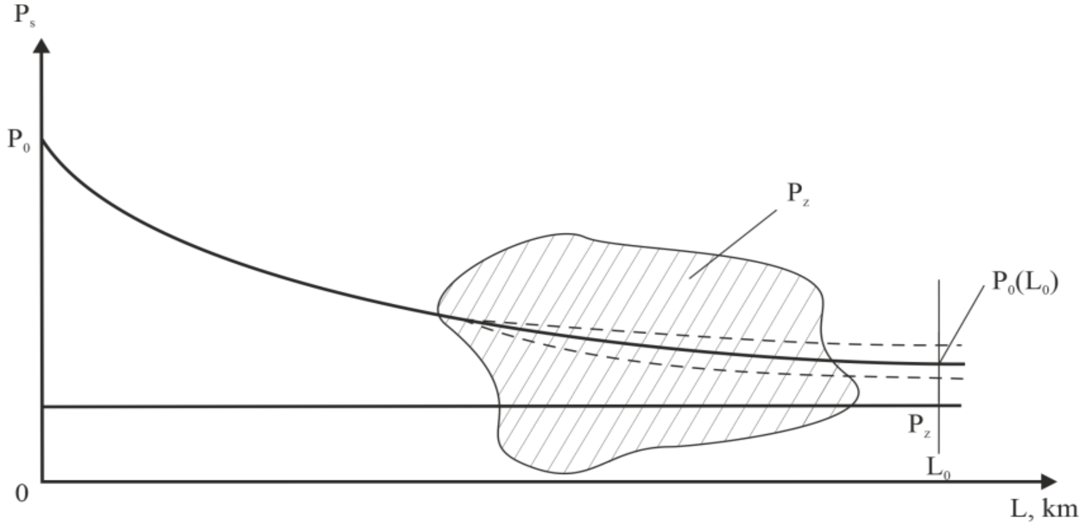

Figure 4: Single-laser system for transmission of amplitude-manipulated signals under conditions of multiplicative interference

The disadvantage of this method is the inability to reliably transmit information using an open optical communication line with a single laser beam under the influence of multiplicative noise (snow, rain, fog), the intense changes of which can be one or two orders of magnitude greater than the intensity of amplitudes signal signs "0" and "1" on the receiving side of the communication channel.

A method of data transmitting is proposed in [19] work. It is used simultaneously two light emitters with different wavelengths and two optical communication lines.

The attenuation characteristic of such a binary-manipulated signal is shown in Fig.5 depending on the distance from the optical signal source.

The information bits "1" and "0" are manipulated on one of the channels, and the second channel is used as a reference.

Thus, the effect of multiplicative interference on the signals of optical communication lines is virtually identical, and the change in their intensity does not affect the received difference signal, which becomes the corresponding signs "1" and "0" of transmitted messages.

The structure of an optical data transmission system is shown in Fig.6 [19].

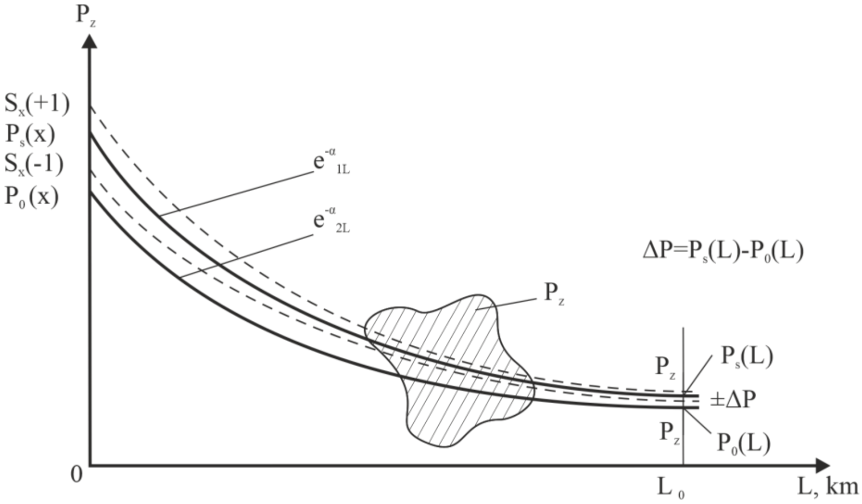

Figure 5: Double laser system for transmission of amplitude-manipulated signals under the influence of multiplicative interference

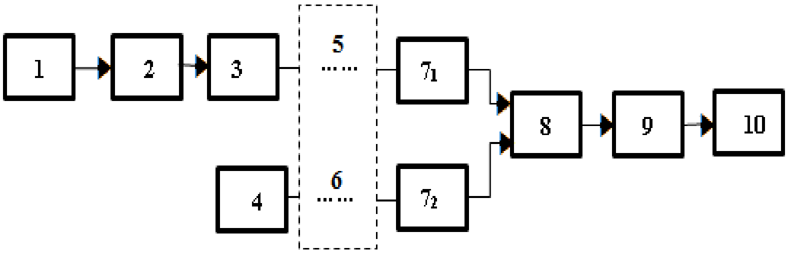

Figure 6: The structure of the optical data transmission system protected from multiplicative atmospheric interference

The components of such a system are:
1 - source of information;
2 - channel encoder;
3 - the first emitter of manipulated optical signals;
4 - the second emitter of unmanipulated optical signals;
5,6 - the first and second open optical communication lines, respectively
7_1, 7_2 - appropriate receivers of manipulated and non-manipulated optical signals;
8 - differential signal receiver; 9 - channel decoder; 10 - receiver of information message.

In Fig. 7 shows a diagram of digital processing of amplitude-manipulated optical signals on the receiving side of the telecommunication channel under the influence of multiplicative interference [19].

The functional limitations of this method are low noise immunity of amplitude-manipulated optical signals receiving, under the influence of flickering of optical rays in the air polluted environment and influence of receivers' amplifiers own noise for light laser beams.

In order to increase the noise immunity of binary-manipulated optical signals, a method of forming differentially-manipulated signals is proposed [19], the attenuation characteristic of which is presented in Fig. 8.

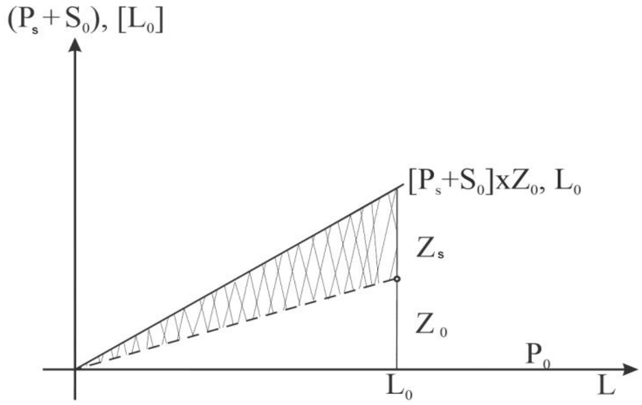

Figure 7: Characteristics of reliable receiving of amplitude-manipulated optical signals [P_s x Z_0] in comparison with the power of multiplicative interference Z_0.

P_c -power of light flux of amplitude-manipulated double signals P_0 - power of the reference flux of light radiation.

Reliable receiving of amplitude-manipulated signals in the conditions of multiplicative interference should correspond to C. Shannon's fundamental limitation $\frac{P_C}{Z_0} \geq 2$.

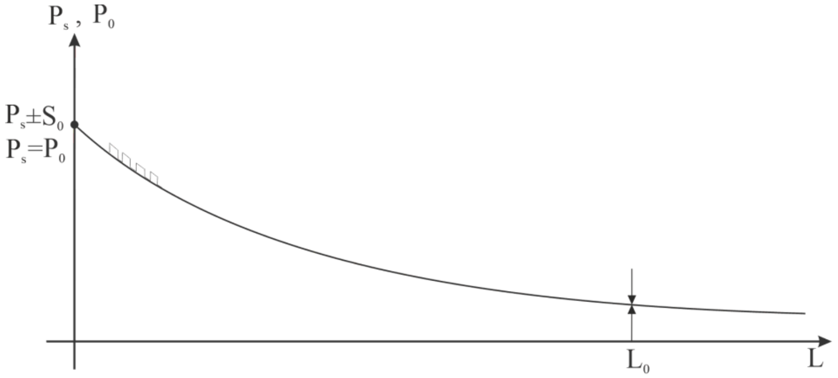

Figure 8: Characteristics of attenuation of binary- and differential-manipulated optical attenuation signals from the propagation distance L

It is shown a diagram (Fig. 9) of digital processing of differentially manipulated optical signal under conditions of multiplicative interference.

The positive effect is the practical absence of the influence of multiplicative interference on the distortion of "1" and "0" information bits. This is achieved by the additional introduction of two emitters of the same power and different spectrum of differentially manipulated and reference non-manipulated optical channel.

This simplifies the demodulation of the transmitted information bits by determining the differential-comparative difference between the manipulated and non-manipulated optical signals on the receiving side of the information transmission system.

4. Laser telecommunication and sensor CPS systems in the territories of nature protection objects

Section 2 of this publication systematizes the functions and characteristics of protected areas as sources of information. It is emphasized that an important impact on the flora and fauna of protected areas in winter is the information characteristics of the height of snow cover.

There is a method for measuring the height of snow cover, which is implemented in the form of a metrological calibrated rail with height marking [8].

The disadvantage of this method is the limited functionality, which is due to the fact that this device does not allow to register the height of snow cover at the measuring point with GPS coordinate identification and optical communication transmission of data over the sensor network.

This method requires measurement operations on the route of monitoring by a human operator in the winter weather conditions.

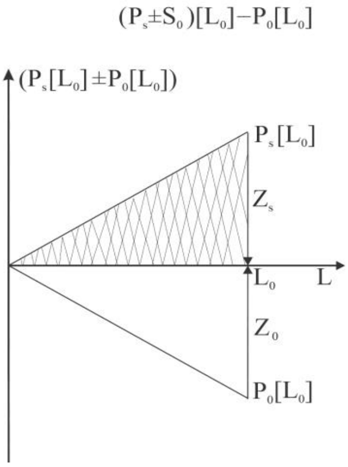

Figure 9: Diagram of differentially manipulated optical signal digital processing

The proposed method has advanced functionality based on the use of transceivers with double signal manipulation of optical signals [15,19]. At the same time, remote measurement of snow cover is carried out on a specific route with GPS identification of sensor system components and autonomous power supply of each of the sensors from a renewable energy source.

It is shown the structure (Fig. 10) of the proposed bus-relay sensor system for measuring the height of snow cover [8,15].

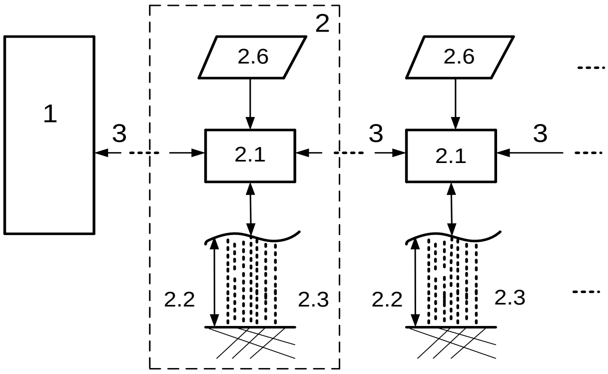

Figure 10: Structure of bus-relay sensor system for measuring the height of snow cover

The components of such a system are: 1 - subscriber station, 2 - sensors of snow cover height, 3 - atmospheric optical communication lines.

It is shown the structure (Fig. 11) of the sensor for measuring the height of the snow cover as a network component of the sensor system [15].

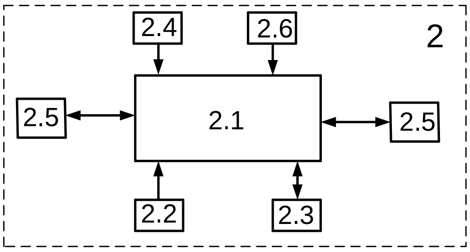

Figure 11: The structure of the sensor for measuring the height of the snow cover

The components of such a sensor are:

2.1 - module for collecting, processing and transmitting information;
2.2 - calibrated rail height of snow cover;
2.3 - optical meter of snow cover height;
2.4 - GPS tracker;
2.5 - optical transceiver;
2.6 - solar power panel of the sensor.

In order to expand the functionality of this class of CPS systems, the authors proposed a multi-sensor system for measuring the height of snow cover [15]. The architecture of this system is shown in Fig. 12.

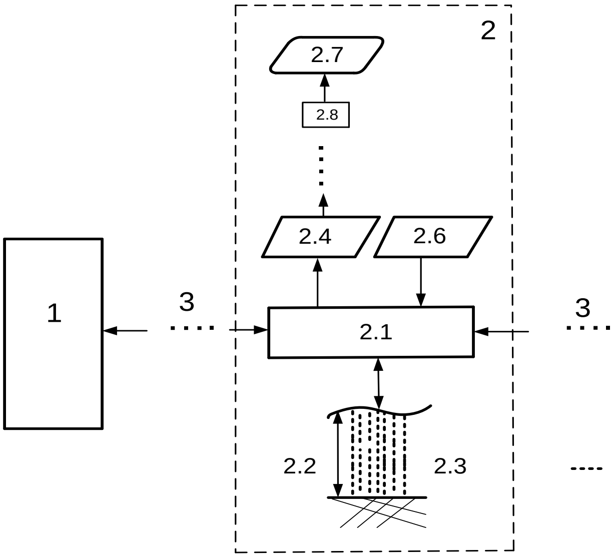

Figure 12: Architecture of multi-sensor system for measuring the height of snow cover

Extended functionality of such a multisensory system is achieved by additional adding into its structure a quadcopter (2.7), which allows parallel processes of information collection by unmanned aerial vehicles (UAVs), as well as remove GPS trackers from the microelectronic sensors (2.1). Non-interactive optical communication of the quadcopter receiver is carried out by vertically directed optical emitters (2.4).

The development and practical implementation of multi-channel autonomous microcontrollers (MC) is a further research of a stand-alone CPS component with wireless optical communication for the territory of nature protection areas. These MCs are components of subscriber stations (ST) that are designed to collect data from a multi-channel sensor network in the CPS architecture shown in Fig. 2.

5. Methods and processor tools for sorting data of arrays

Sorting is one of the typical problems of data processing and is usually understood as the task of placing elements of an unordered set of values of data sets, in the order of monotonic increase or decrease [20-22]. The operation is most often used in communication stations of CPS network architectures, as well as in algorithms for digital signal and image processing when storing large data sets by archiving and compressing them. Many methods of sequential and parallel sorting of binary data are known [21-23].

There are methods of data ordering, in which the sequence of operations depends only on the number of input data and does not depend on the values of their keys. Among them, the most practical applications were the corresponding structures of Butcher's algorithms, modified "bubble" algorithm, "odd-even" permutation algorithm [23], merger algorithm, "perfect shuffling" algorithm and others. Important parameters of the efficiency of these algorithms are the speed of formation of an ordered data set and the number of operations performed.

It is shown the proposed structure (Fig. 13) of the algorithm of the Kautz sorting network [23].

The proposed structure of the sorting network algorithm consists of the same type of operations "compare and rearrange". For N input number of “compare-and-swap” instructions for this proposed structure for comparing arrays of data will be equal to - $3((N/2)^2- N/2))/2+N/2$.

The structure of the basic component of the ordering of X_i and Y_{i+1} data streams is shown in Fig. 14 [23].

At hardware special processor realization of such basic component its efficiency is defined by two structures:

A structure [23] for comparing two binary codes based on the use of half-adders is proposed (Fig. 15).

The number of adders is equal to the bit size of the compared codes.

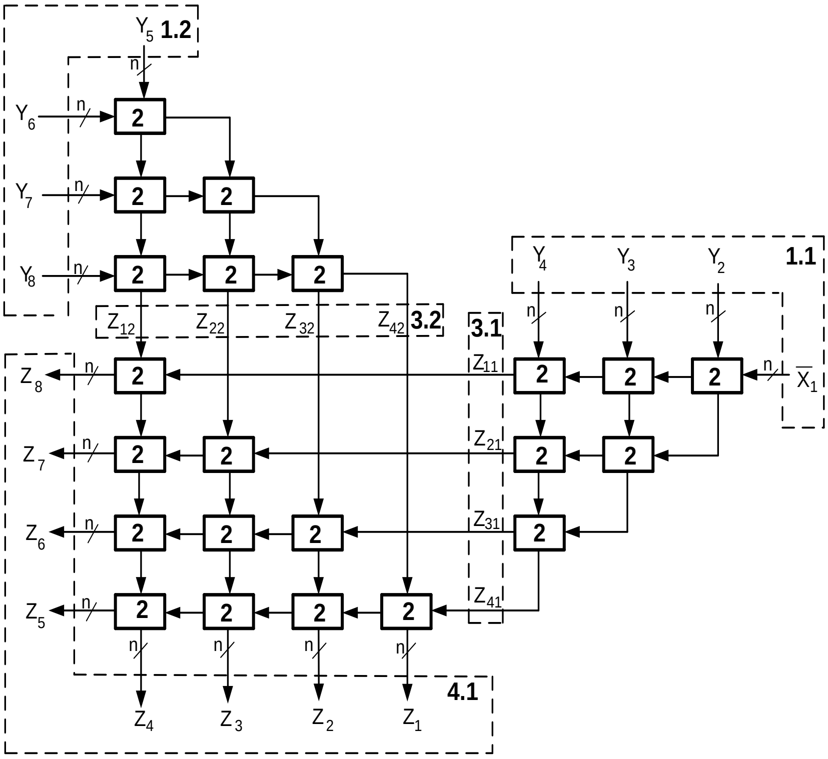

Figure 13: The proposed structure of the sorting network

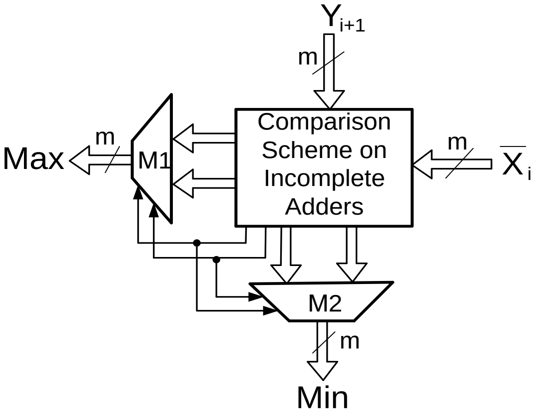

Figure 14: Block diagram of the basic component of ordering binary numbers

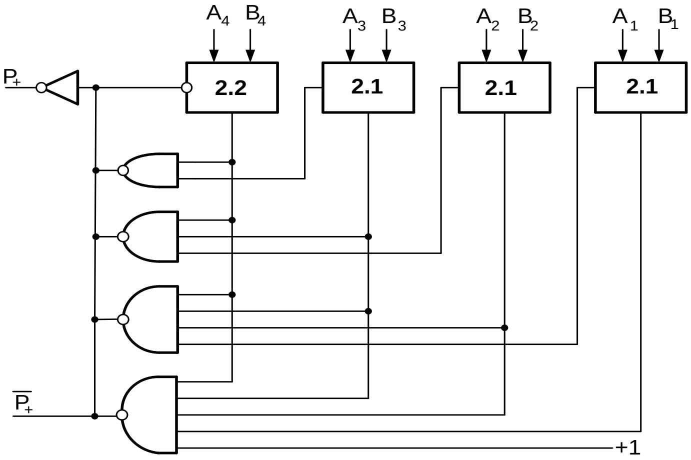

Figure 15: Scheme of comparison of two multi-bit binary codes, 2.1, 2,2 – one-bit half adders

The advantage of the proposed structure is high regularity, maximum speed of bit formation of the comparison signs and logarithmic increase in the number of logical elements "AND-NOT" whose outputs are interconnected. The comparison operation is based on the operation of adding direct and inverse data codes, the source of which is the overflow of the bit grid.

Using incomplete single-bit adders [24] is proposed as components of this structure of comparison of multi-bit binary codes (Fig. 16).

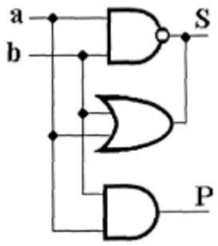

Figure 16: Block diagram of a single-bit half-adder (a, b - input bits, S - sum bit, P - carry bit)

The speed of the proposed comparison component is a delay of signals for 2 micro-clocks, regardless of the bit size of the input codes.

It is shown the proposed structure (Fig. 17) of a multi-bit multiplexer with paraphase outputs based on logical elements "AND-NOT" [23].

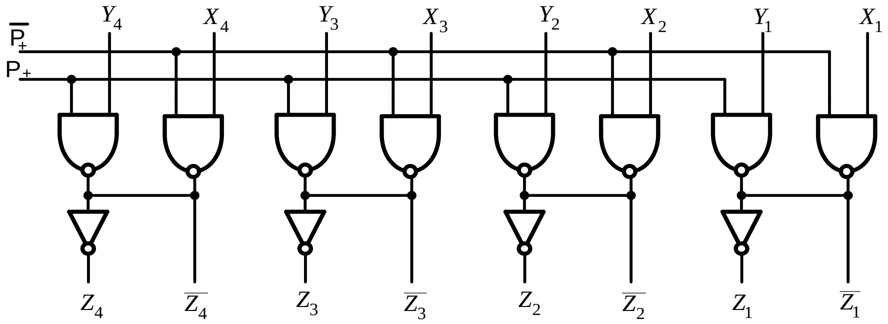

Figure 17: Block diagram of a multi-bit multiplexer with logic elements "AND-NOT"

The speed of such a multiplexer is determined by the delay of signals at the inverse outputs - 1 micro-clock, and at direct outputs - 2 micro-clocks. This multiplex is characterized by advanced functionality and circuitry consistent with the components of the comparison of numbers in which the operation of adding direct and inverse codes.

A further increase in speed and reduction of hardware complexity of this class of multiplexers is the use of one logical element "AND-NOT" or "OR" in each category. It is shown the structure (Fig.

18) of a high-performance multi-bit multiplexer based on the logic element "Exclusive OR", which implements the logic operation "XOR" [24]. This multiplexer does not have a control input inverter that provides the operation of multiplexing two multi-bit binary codes with a delay of signals per microcontroller.

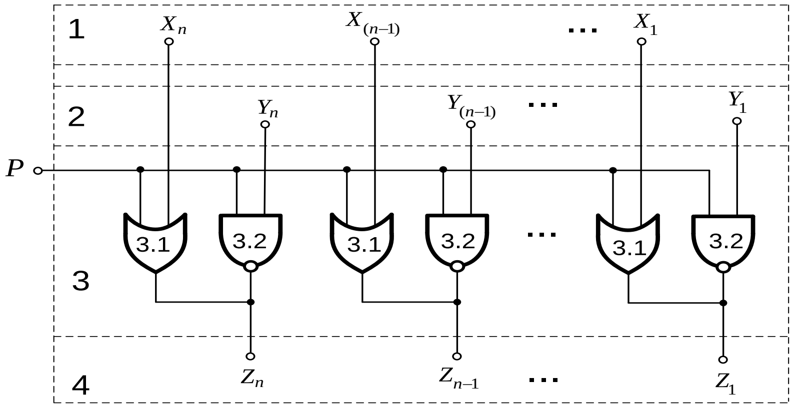

Figure 18: Block diagram of a multi-bit multiplexer with the logic element "Exclusive OR" with direct output

The block diagram of a multi-bit multiplexer contains: 1 - the first input information bus (X_n, X_{n-1},…, X_1); 2 - the second input information bus (Y_n, Y_{n-1},…, Y_1); 3.1, 3.2 - logical elements OR and AND-NOT bits of the multiplexer; 4- output information bus (Z_n, Z_{n-1},…, Z_1).

The proposed components of the basic operation of comparing numbers and their multiplex permutation, as well as the parallel Kautz algorithm allowed to increase the ordering speed by 1-2 orders of magnitude, with bit input n = 32-128 bits.

6. Conclusion

The basic principles of building modern cyber-physical systems (CPS) are outlined and the priority areas of CPS application are emphasized. Prospects for the use of open optical data transmission channels with binary-manipulated signals are substantiated. Structures of special processors of formation and digital processing of binary-manipulated optical signals are offered. New components and high-performance structures have been developed to streamline priority information flows.

7. References

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