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CURRENT STATE OF DEVELOPMENT OF INTELLIGENT INFORMATION AND MEASURING SYSTEMS FOR ENVIRONMENTAL MONITORING WITH MULTISENSOR CONFIGURATION

The paper presents an analysis of literature sources (literature review) on the use of methods and means of intellectualization of information-measuring systems with multisensor configuration. The need for continuous monitoring of quality of life parameters in real time involves the use of low-cost information and measurement monitoring systems based on IoT. Each device has a unique identification and the ability to autonomously collect data in real time. The basic building blocks of IoT consist of sensors, processors, gateways and applications. Information – measuring systems perform the functions of control and regulation in the house – lighting, temperature, security, acoustics, fire safety. In this situation, a smart home resembles an ecosystem controlled by a central "brain" and controlled by a smartphone. To control the security of the house – on the transition to the fire detection system, unauthorized intrusion, using several technologies based on social networks. To control the parameters favorable for the growth of plants in greenhouses, and to ensure maximum yield of fruits and flowers, soil temperature and humidity, air temperature and humidity, carbon dioxide (CO_2) content in the air and lighting intensity are monitored. Fuzzy logic ensures high accuracy of data acquisition. The process establishes a connection from the mid-range and sends a message in a short period of time to the smartphone to notify about certain situations. This system can also be used for surveillance by changing the BLE module to a GSM module and changing some operators, especially the AT command. Also discussed is the architecture of multi-sensor data fusion is one of the key challenges in designing a multi-sensor system. The emergence of systems with a large number of sensors, such as the Internet of Things, can introduce novelty to this well-studied topic. In this study we consider three aspects of MSDF architecture: classification, optimal selection and standardized presentation. Based on the analysis, we propose our own structural and architectural solutions for similar multi-sensor systems.

Key words: *multisensor, wireless sensor, multisensor monitoring system, smart home, artificial intelligence, artificial neural network, IoT.*

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СУЧАСНИЙ СТАН РОЗВИТКУ ІНТЕЛЕКТУАЛЬНИХ ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНИХ СИСТЕМ ЕКОЛОГІЧНОГО МОНІТОРИНГУ З МУЛЬТИСЕНСОРНОЮ КОНФІГУРАЦІЄЮ

В роботі представлено аналіз літературних джерел (літературний огляд) із застосування методів та засобів інтелектуалізації інформаційно-вимірювальних систем з мультисенсорною конфігурацією. Потреба у постійному моніторингу параметрів якості життя в режимі реального часу передбачає використання недорогих інформаційно-вимірювальних систем моніторингу на основі IoT. Кожен пристрій має унікальну ідентифікацію можливість автономного збору даних у режимі реального часу. Основні конструктивні блоки IoT складаються з датчиків, процесорів, шлюзів та додатків. Інформаційно – вимірювальні системи виконують функції контролю та регулювання в будинку – освітленням, температурою, безпекою, акустикою, пожежною безпекою. У цій ситуації розумний будинок нагадує екосистему, якою керує центральний «мозок» і керується за допомогою смартфона. Для контролю за безпекою будинку – на переході до системи виявлення пожежі, несанкціонованого проникнення, із застосуванням декількох технологій, заснованих на соціальних мережах. Для контролю параметрів сприятливих для росту рослин у теплицях, та забезпечення максимальній врожайності плодів та квітів контролюють температуру ґрунту і його вологість, температуру та вологість повітря, вміст вуглекислого газ (CO_2) у повітрі та інтенсивністю освітлення. Нечітка логіка забезпечує високу точність отримання даних.

Процес встановлює зв'язок із середнього діапазону і надсилає повідомлення в короткий період часу на смартфон для повідомлення про ті чи інші ситуації. Ця система також може використовуватися для спостереження, змінивши модуль BLE на модуль GSM і змінивши деякі оператори, особливо AT-команду. Також розглядається архітектури мультисенсорного злиття даних є одним із ключових завдань при проектуванні мультисенсорної системи. Поява систем з великою кількістю датчиків, наприклад Інтернет речей, може ввести новинку в цю добре вивчену тему. У цьому дослідженні ми розглядаємо три аспекти архітектури MSDF: класифікацію, оптимальний вибір та стандартизовану презентацію. На основі проведеного аналізу запропоновано власні структурні та архітектурні рішення для аналогічних мультисенсорних систем.

Ключові слова: *мультисенсор, бездротовий датчик, мультисенсорна система моніторингу, розумний дім, штучний інтелект, штучна нейронна мережа , IoT.*

Introduction

Today, there is a need for constant monitoring of a significant number of parameters of one or another environment, etc., in real time [1–3]. Control systems using a large number of devices using the concept of the Internet of Things (IoT) are usually used for this purpose [4–7]. Each of these devices has a unique identification and must be able to collect data autonomously in real time. Typically, the main building blocks of the IoT include sensors, important components of complex information and measurement systems, processors, gateways and applications.

Therefore, the development of wireless sensor network (WSN) and wireless technology to provide assistance in personal and professional daily human needs is relevant. In recent decades, wireless technology applications have been developed for data acquisition, control, environmental monitoring systems, and automation of manufacturing processes [7–10]. Modern wireless networks have more advantages, such as low costs for both installation and maintenance, as well as long uptime. A remote sensor network can be used for fixed or mobile sensor networks. It is commonly used for various purposes such as urban infrastructure development survey, environmental monitoring, telemedicine or remote health care, agricultural research, fisheries monitoring, farming, border security, traffic management, forestry management and disaster prevention [10–12]. A WSN consists of compactly distributed sensor nodes for sensing, signal processing, embedded computing, and connectivity. This system provides interaction between people or computers and the environment using wireless communication. Although WSNs were originally used in military and heavy industrial applications, modern WSN applications are used for various purposes, from light to heavy industrial systems [13].

A WSN system allows users to monitor and control connected devices from a base station using various wireless communication standards, such as Wi-Fi, General Packet Radio Service (GPRS), Bluetooth, ZigBee, Radio Frequency Identification (RFID), and cellular technologies. Users can track data over a wireless network that may be designed based on one of these wireless standards [13]. The advantages of WSN are low power consumption, excessive data acquisition, remote monitoring, fast network establishment, wide coverage area, high monitoring accuracy, and low duty cycle. Thus, WSNs in the real world are practically not limited to physical security, environmental monitoring, and climate change. Positioning and tracking from healthcare to logistics, localization and more. IoT was developed in parallel with WSN and is a physical network that connects all things to exchange data and information through data sensing devices such as sensors, actuators and computers according to relevant protocols. These aspects are especially important in the case of environmental monitoring systems.

Purpose of work

The purpose of the work is to analyze the developed approaches to the intellectualization of information and measurement systems of environmental control with a multi-sensor configuration, and then to design similar systems for microclimate monitoring.

Analysis of sensor systems for environmental monitoring

There are many IoT applications, such as RFID tags, sensor technologies, mobile technologies, and other intelligent technologies [14]. Shruti Sridharan et al., [15] proposed an effective wireless sensor network (WSN)-based water quality monitoring system that analyzes water quality for irrigation. R. Karthik Kumar et al [16] investigated an underwater wireless sensor network powered by a solar panel for water quality monitoring. Through the WSN, various data such as pH, turbidity, oxygen content collected by certain sensors of the node are sent to the base station. The collected data is then visualized and analyzed using various modeling tools. Marco Zennaro, Athanasios FloroSs, Gokhan Doga et al., [17] proposed a water quality monitoring system design and, based on Sunspot technology, a wireless sensor network (WQWSN) implementation prototype as a solution to the water quality monitoring problem. Kirankumar G. Sutar, Professor Ramesh T. Patil [18] presented a system for monitoring the water quality of fisheries based on a wireless sensor network. The system consists of a base station and sensor nodes. The determined parameters with their exact values are transmitted to the monitoring station via wireless communication, and the details are controlled by the administrator. The indicator signals that the threshold values of the parameters are exceeded. The system has such advantages as low power consumption, more flexible in deployment. ACKhetre, Prof.SGHate [19] also investigated a wireless sensor network for an aquatic environment monitoring system that provides on-line monitoring of temperature, turbidity, water level and salinity.

Brinda Das, PC Jain proposed a real-time water quality monitoring system using IoT [20]. The usual method of testing water quality is to collect samples by hand and send them to a laboratory for testing and analysis. This method is time-consuming and uneconomical. The proposed system checks water quality using various sensors (one for each parameter: pH, conductivity, temperature). The ZigBee module in the system transmits the data collected by the sensors to the microcontroller wirelessly, and the GSM module transmits the data wirelessly further from the microcontroller to the smartphone / PC. The system also has proximity sensors that warn of pollution by sending a message via a GSM module in case someone tries to pollute the water body.

M. Saravanan, Arindam Das, and Vishak Iyer proposed intelligent management of water networks using LPWAN IoT technology [21]. A new Low Power Wideband Network (LPWAN) technology called LoRa has been used to connect IoT devices. LoRa devices can exchange data within 2-4 km, working on batteries. The proposed water network management system includes sensors deployed at various strategically selected locations to measure water quality by generating real-time data. The system also provides an alert mechanism that reports issues via email and SMS. The sensors with the microcontroller in the LoRa module will communicate with the cloud environment through the LoRa gateway. The web page provides an interface to assess water quality after analyzing the data using a prediction algorithm.

Himadri Nath Saha, Supratim Oddi, Avimita, et al. presented a pollution control system using IoT [22]. The proposed system uses an ultraviolet light sensor that outputs an analog signal about the amount of UV light extracted, as well as a water temperature and PH sensor to monitor water quality, temperature, turbidity, etc. The collected parameters or settings are sent to the cloud. Cesar Encinasn, Erica Ruizi et al., [23] proposed an IoT system for aquaculture water quality monitoring that monitors water quality using wireless sensor networks and IoT to optimize pond maintenance resources. Josef Konyga [24] proposed a grid-based water quality measurement system for wide areas. It is a prototype of an easy-to-install technology that can be used to measure various surface water quality indicators. Thanks to the modular design of the tube sensor, it is possible to measure from 1 to 7 indicators. The Wide Area Measurement System (WAMS) exchanges information via the GPRS network. Pradeep Kumar, Somasundaram and Daron Joseph [25] proposed real-time RF module water quality monitoring. The system includes a pH level sensor, a temperature sensor and a turbidity sensor (LED-LDR-mount). The measured indicators are transmitted to a remote base station using an RF module (2.4 GHz), which makes monitoring in a remote format convenient. Zhu Wang Qi Wang, Xiaoqiang Hao [26] discussed the problem of manual analytical method of real-time water quality assessment and presented a WSN-based remote water quality measurement and control system

Raja Vara Prasad Y, Mirza Sami Baig, Rahul K. Mishra et.al., [27] proposed a system that integrated technologies such as frequency hopping and virtual instruments to perform wireless data transmission for air quality monitoring. The carrier frequency is adjusted according to the result and the full radio frequency spectrum is used. Wireless data transfer is carried out without interfering with the test sample in real time. The resulting data is easy to read and clearly displayed.

Devarakonda, S., Sevusu, P., L., H., Liu, R., Iftode, et al., [28] proposed a system for real-time air pollution control using WSN. The CO2 and NO2 gas sensors are calibrated using calibration techniques, and then the WSN is formed using a multi-hop data aggregation algorithm. Pollution data is displayed as numbers and charts via a web interface and is also available online. Temperature and humidity parameters are measured together with the gases, and the data is analyzed with synthesis data.

Cho Jin Myint, Lenin Gopal, and Yang Lin Aung [29] presented a reconfigurable smart water quality monitoring system in an IoT environment. A reconfigurable intelligent sensor device is proposed in the work. The WQM smart system consists of a Field Programmable Gate Array (FPGA) board, sensors, a ZigBee-based wireless communication module, and a personal computer (PC). The FPGA board is the main component of the proposed system and it is programmed in Integrated Circuit Hardware Description Language (VHDL) and C programming language using Quartus II software and Qsys tool. This WQM system collects information on such parameters as water pH level and turbidity. Shailaja M., Gunda Nikkam, Dr. VR. Pawar [30] proposed a water parameter analysis system for industrial applications using IoT. IoT technologies, WSN and communication standards are adapted to the system. IoT and WSN are used to collect data about physical things using a standard communication protocol. The performance analysis of the proposed system is carried out by collecting data of water parameters from various sensitive sensor elements (turbidity, density, temperature and pH) at the base station and comparing it with its threshold value at the monitoring unit.

Octavian Postolash, José Díaz Pereira, and Pedro Silva Girão [31] presented wireless sensor solutions for environmental monitoring. This study proposes a wireless sensor network architecture that combines multi-parameter sensing nodes for reliable monitoring of water quality parameters of surface waters. Special attention is paid to the design of conditioning circuits for conductance, temperature, and turbidity signals, highlighting important issues related to linearization, dynamic range measurement, and implementation of commercial components and devices. A.N.Prasad, K.A. Mamun et al., [32] proposed a smart water quality monitoring system for o. Fiji based on IoT and remote sensing technology. In the system proposed by N. Vijayakumar R. Ramya [33], monitoring of water quality in real time is carried out by monitoring temperature, pH, turbidity, conductivity. Raspberry Pi B+ has been exposed as the main controller for edge computing. The received data is transferred to the cloud. Vinod Raut and Sushama Shelke [34] proposed a wireless procurement system for water quality monitoring. The proposed system is focused on the development of a wireless collection system, which is the main element of the water quality monitoring system, and remotely measures water turbidity and pH. The system is built using a Peripheral Interface Controller (PIC) microcontroller and consists of two sections, namely: a transmitter section that collects pH and turbidity readings from a remote location, and a receiver section that collects the transmitted readings using the ZigBee wireless communication protocol. The results are classified into three classes using different levels of pH and turbidity to obtain a water quality index. The results are displayed on the LCD screen as well as on the PC for different time periods.

In all analyzed systems, air and water quality sensors such as pH, temperature, turbidity, CO_2 sensors and MQ sensors are connected to the microcontroller unit for further processing. The serial communication unit acts as a phase between the MCU and the GPRS module, the GPRS module transmits the data to the workstation, and later the data is stored in the cloud for further use. Most of the sensors used will give an analog output to the ADC present in the controller, the measured data is transmitted using a GPRS module connected to the microcontroller using the UART protocol.

Similar systems, when changing the configuration of sensors, can be used for biomedical diagnostics, household and production, etc. [35]. For example, the system of biomedical diagnostics can be used for general management of the state of health of the body in both industrial and everyday environments. In such systems, the collected and converted microelectrical signal from the sensors is first restored as a result of a complex computational process. Further, the information is transmitted with the participation of an artificial neural network (ANN), which is connected to the Internet through a built-in communication function.

Structures information and measurement system for monitoring in the concept of IoT

A typical IoT-based information and measurement system for monitoring certain parameters consists of a set of sensors, a readout integrated circuit (ROIC), control and communication modules such as a microcontroller unit (MCU) and a Bluetooth interface that can interact with a smartphone and apply to different applications using the communication function. Thus, a smartphone or laptop illustrates a convenient exchange of information using a communication module. Each sensor converts the change in electrical signals into voltage, current, resistance, and capacitance. In the case of voltage and current, a high-efficiency analog-to-digital converter (ADC) can convert to a digital code that is used for control and communication for the MCU. To process resistance and capacitance information, the ROIC consists of an interface and an ADC that includes the acquisition, processing, and conversion of sensor signals. Hence, a specific ROIC is functionally required to process changes to its sensor in the system. The reconfigurable ROIC has advantages that support IoT compatibility and save ROIC manufacturing costs.

An important aspect of such information and measurement systems, which are implemented on the basis of IoT technology, is the use of artificial neural networks (ANN) for effective calculations based on measured parameters. It is known that the modern ANN is one of the computing systems that contains a learning unit and a decision-making unit. ANN is also called a multilayer perceptron (MLP), which consists of an input layer, a hidden layer, and an output layer (Fig. 1) [36]. The weights of the hidden layers are optimized taking into account the characteristics of the data and patterns. Layers can be extended to easily handle complex data and system.

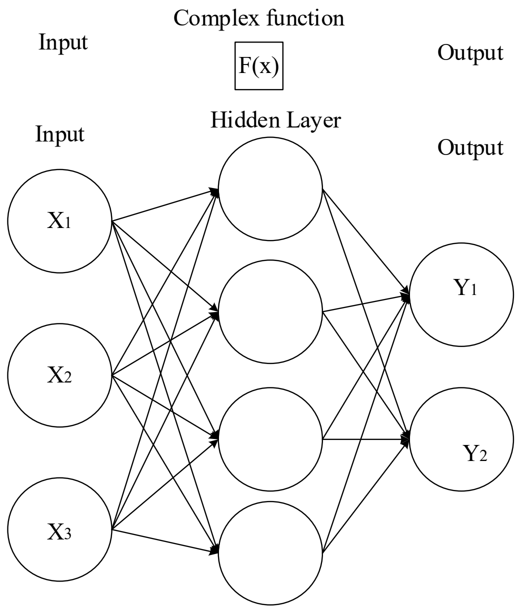

Fig. 1. The structure of a typical artificial neural network (ANN) with a learning algorithm

Conventional sensor systems process and analyze only the output data of the system. However, by developing an ROIC that can be displayed by feedback from the analysis, the overall performance of the system can be effectively improved. This thesis explains the previous reconfigured system, the sensor system and the ADC. Different types of sensors require appropriate readout interfaces, and different applications require that each interface meet application-specific characteristics. However, simply integrating different sensor interfaces into a single ROIC does not make sense and does not reflect the different requirements. Another trend is that they are increasingly incorporating additional functions by processing data collected from multiple sensors. Developing an appropriate ROIC is not easy, and it can be inefficient in terms of overall system implementation. Therefore, it is necessary to implement a multifunctional ROIC for sensing the signal of several sensors.

Most sensors convert a sensitive signal into an electrical signal, which is expressed as voltage, current, resistance, and capacitance. Each ROIC has different performance, range, resolution, conversion ratio, etc. For example, a touch screen panel (TSP) can be processed with a switched-capacitor amplifier depending on the capacitance change, and the sensor can perform its functions with the same circuit if only the required gain or electrode capacitance is adjusted. To control the processor and wireless communication, the collected signals are digitized by an ADC. A reconfigurable ADC is used to adjust the resolution.

In the most typical monitoring systems, in order to meet the industrial demand, an Arduino board is used as a hardware platform for processing the data of several sensors [37]. It is an open source microcontroller platform that allows connecting a variety of sensors and devices [37]. In [37], an Arduino Uno board based on Wi-Fi was chosen to form the sensor nodes. In addition, a local database is developed to host and manage data from multiple sensors, and big data technology through Apache Spark is implemented to organize the resulting numerical data and support further data fusion and analysis. Due to the wireless sensor network feature, the system can be easily expanded by adding more sensors. The proposed structure of the monitoring system is shown in fig. 2.

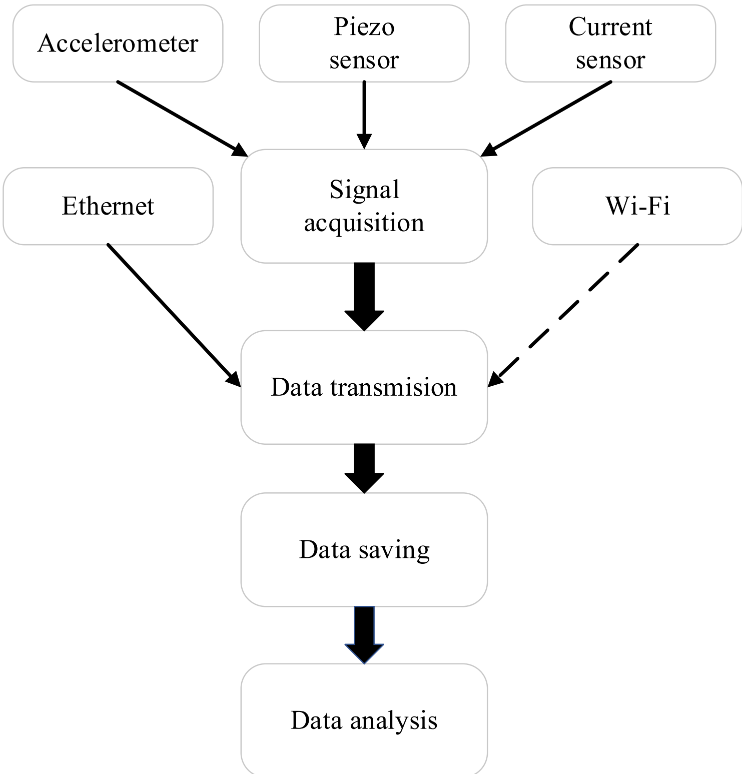

Fig. 2. Data monitoring and analysis system

An important component in any intelligent information and measurement systems is a device with a Wi-Fi multi-sensor element [37]. It is worth noting that multisensors must monitor data, inform about the state of the environment (around the house, etc.) and support any requirements in the conditions of a digital society. A significant amount of work is devoted to the design of smart houses, an important aspect of which is the multi-sensor configuration [38]. In particular, home security monitoring, fire detection using multiple technologies based on social networks is an important point. Multisensor calibration is known to use calibration time, and self-calibration uses a Finite Impulse Response (FIR) filter.

Next, a full-scale Kalman filter (FSKF) helps fill the data and estimate the accuracy. The fire detection engine then uses fuzzy logic to detect and send warning messages during the IF This Then That (IFTTT) period. A home event changes multi-touch Wi-Fi data. The effect of data range on the proportion of fires inside the house was taken. A multi-sensor Wi-Fi node should use more than one detector, which will have high stability and high accuracy [37]. Developed methodologies and devices capable of detecting smoke and fires. They send a warning message to a smartphone via a social network after a Facebook, Gmail or Line message.

Such a surveillance system is equipped with three sensors to measure ambient temperature, relative humidity and fire detection based on social network to check the content of carbon monoxide in the air using a smart Wi-Fi multi-sensor node. The proposed system for predicting the probability of a fire also uses elements of fuzzy logic when processing the values received from the sensors. Data exchange is carried out in the cloud. In addition, IFTTT processing is used to check and receive a message or warning via a social network on a smartphone [38] (Fig. 3). As for the platforms on which such systems are implemented, Arduino, ESP32, Raspberry Pi, ESPresso lite or NodeMCU boards are usually used.

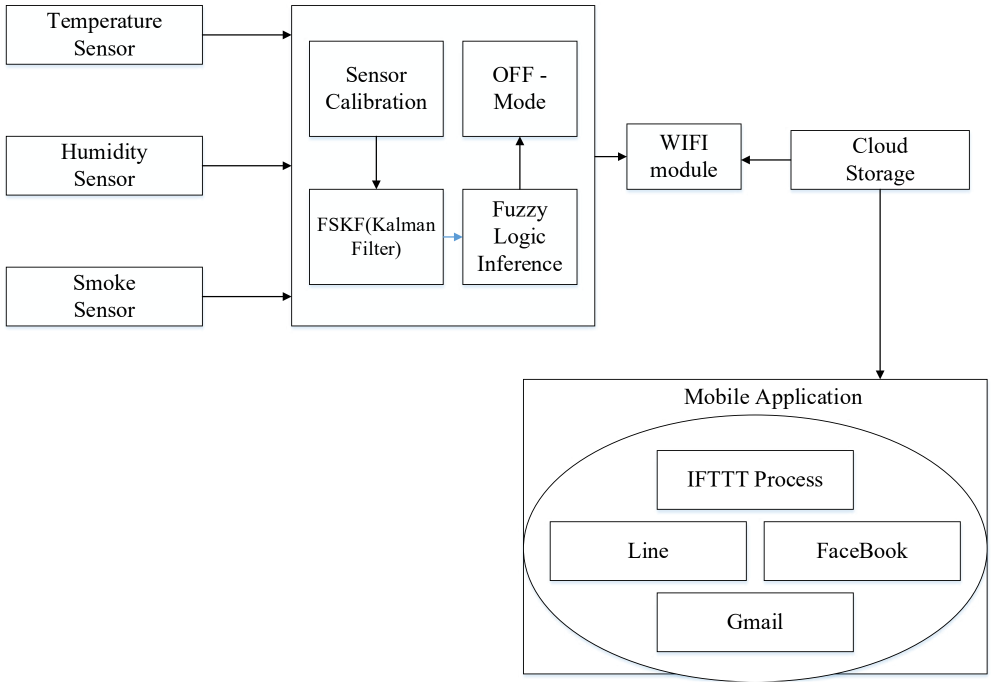

Fig. 3. Microclimate monitoring system with sending notifications through mobile applications

Designing and implementing an environmental monitoring system is challenging because power management, sensor selection, and network type must be considered. In [38], portable sensor nodes are integrated with the existing wireless sensor network infrastructure (Fig. 4). An existing WSN is used to route data from mobile nodes to a cloud server.

The power management system includes a storage battery, a step-up converter, and four-channel SPST switches (ADG811). Switches are used to control the switching on and off of sensors according to different power consumption and applications. Only two switches are used to control the switching on and off of the sensors. The XBee and MCU are configured to turn on and off at the same time. The ATmega328p MCU collects data from each sensor and then sends the data to the base station via a radio frequency link. It also monitors power consumption. The XBee-Pro 900HP module uses the DigiMesh network protocol. The network allows each node to sleep and wake up at the same time. Each node in the network is peer-to-peer and does not require additional routers in the network that cannot be in sleep mode.

Temperature, humidity and pressure data are measured using a BME280 sensor, while CO_2 data is assessed by a COZIR CO_2 sensor. The TSL2591 light sensor can measure the LUX level with low power consumption.

For a fixed location sensor node, each node sleeps and then wakes up to measure. During wake-up, the MCU measures temperature, humidity, pressure, light level and CO_2 values and then packets the data. The XBee checks if an RF channel is available for transmission. If so, the data will be sent to the destination address. After successful data transmission, the entire sensor node will return to sleep mode [39]. Such portable sensor nodes are functionally similar to fixed nodes, except that they need to wake up more often. They can also be programmed to work in a continuous monitoring mode, which will update data according to user requirements. The detailed software algorithm for the portable sensor node is presented in Fig. 5 [39].

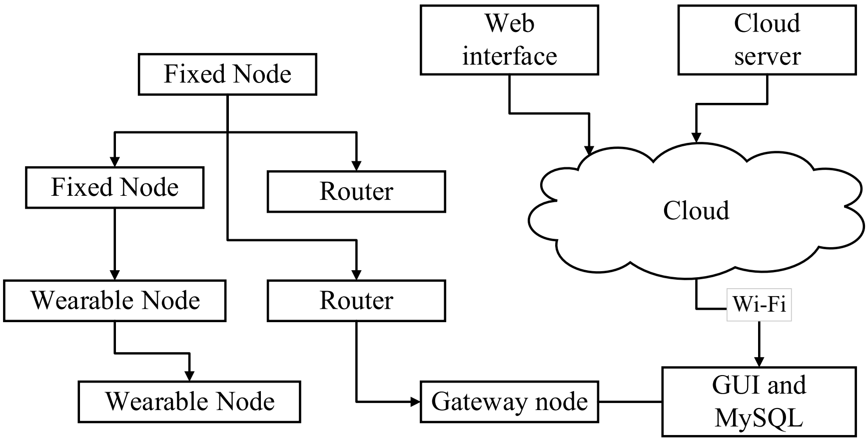

Fig. 4. Architecture and implementation of a system with a wireless sensor network infrastructure

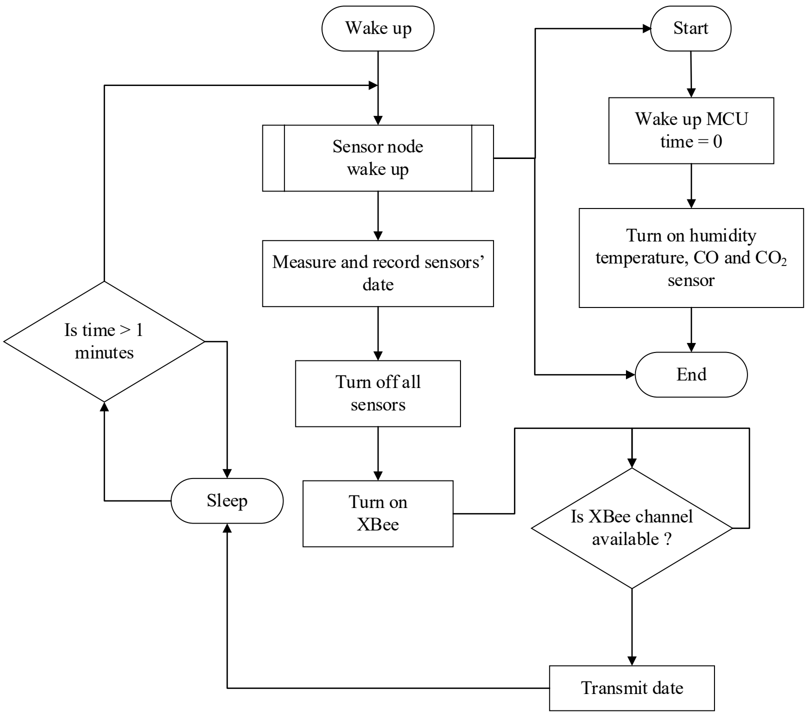

Fig. 5. Software algorithm of the portable sensor node

The base station receives data from both fixed sensor nodes and sensor carriers. It will display the data in a local graphical user interface (GUI) and store the data in a local MySQL database. The data will eventually be transferred to a cloud server via Ethernet [39].

In this case, the network topology is described by the mesh + cluster type. Nodes of sensors of fixed location are mesh-type connections. They wake up periodically to send data. There are also several fixed router nodes to support the communication of sensor nodes, as shown in Fig. 4 [39].

In this paper [40], an automated wireless climate monitoring system in greenhouses is developed in detail, with special emphasis on the programming and testing aspects of the temperature and humidity sensor. The proposed system consists of three blocks: sensor station (SS), coordinator station (SS) and central control station (CSU). The wireless network backbone is based on ZigBee modules for communication between SS and CS, while a proprietary XStream RF modem is used for communication between CS and CCS. Conducted field tests established the functionality and reliability of the designed wireless sensor network. The system can monitor up to six environmental parameters, namely atmospheric temperature, humidity, carbon dioxide (CO_2), light intensity, humidity and soil temperature (Fig. 6).

Design of a multi-sensor integrated system for wireless monitoring of the greenhouse environment. The system has four sensor stations and interacts with the coordinator station using ZigBee RF modules. Long-distance communication between the coordination station and the central control station uses its own RF modem.

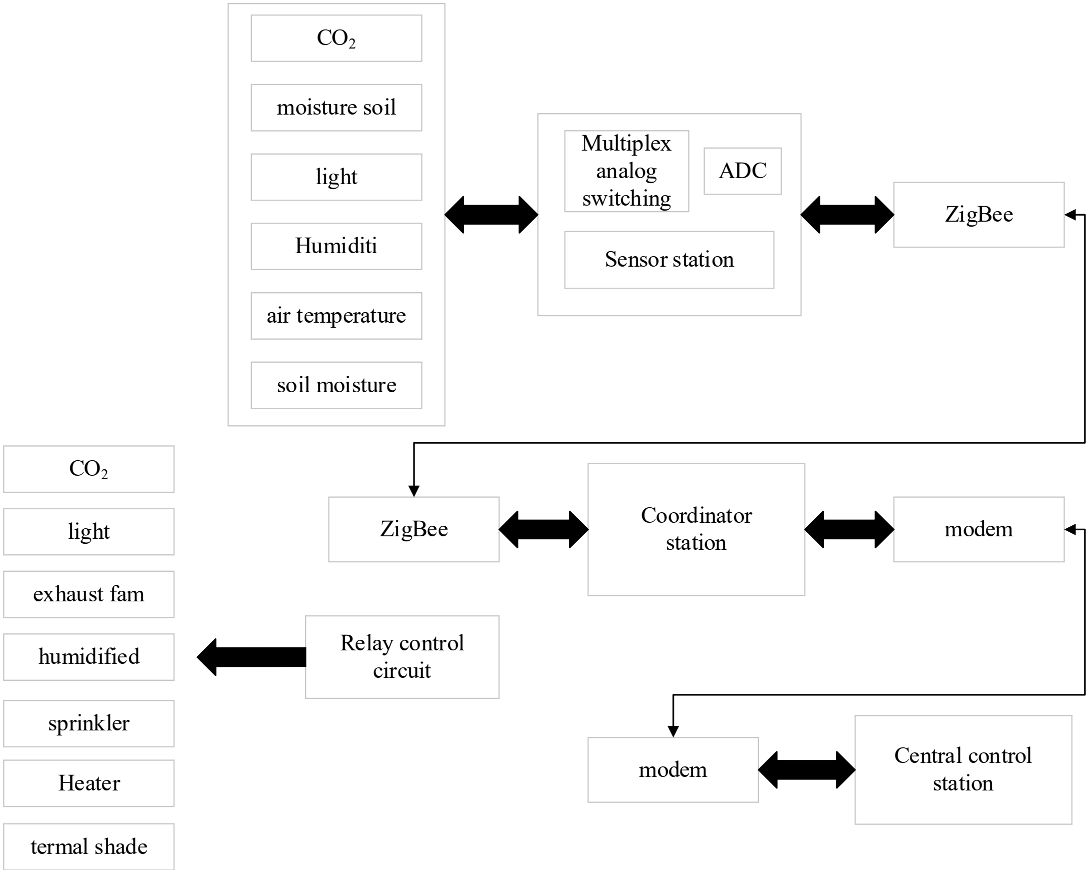

Fig. 6. Functional scheme of the multi-sensor integrated system for wireless monitoring of the greenhouse environment

The sensor station (SS) is responsible for collecting climate measurement data and transmits them to the coordination station (CS). The Coordinator Station acts as a router that preprogrammed the flow of data and instructions between the Sensor Station and the Central Control Station. Also controls on/off sprinklers, humidifier, etc. It communicates with station sensors using the ZigBee wireless protocol and is thus limited to short distances. ZigBee modules are connected to the microcontroller of the coordinator station using UART (universal asynchronous receiver-transmitter). It communicates with the central control station using Xstream RF modems, which are capable of transmitting data using dipole antennas and operate at a frequency of 2.4 GHz. The modem connects to the microcontroller using another UART channel.

The function of the central control station is to issue instructions to lower-level computers, process input data and provide a user-friendly way (allowing users to easily access and visualize them), provide control commands to adjust the greenhouse climatic conditions according to the manufacturer's requirements. The application running on CCS is developed in Visual C#. The program has a convenient graphical interface for monitoring Sensor Station data. Various climate parameters are displayed in real-time using graphs. The CCS is connected to the RF modem via a USB port.

Multi-sensor system using artificial intelligence of the MSDF architecture

Today, multi-sensor systems are becoming an element of design using artificial intelligence Smart Home. Smart home innovations have been around for a while now, with home automation gadgets, software and apps mostly revolving around specific buildings or rooms. The next step in the integration of an artificial intelligent home is the ability to integrate different systems and constantly learn and adapt through sophisticated information surveying. This training procedure controls a unified structure that coordinates important frameworks in the house, such as lighting, insulation, security, sound, blinds, etc. In this situation, a smart house resembles an ecosystem controlled by a central “brain” with the help of a smartphone [41]. Home automation allows a person to remotely or naturally control things around the house.

In the general concept of such automated systems, Alexa from Amazon plays a key role – one artificial intelligence innovation that affects home automation [42]. Alexa's “brain” can be coordinated with various gadgets that have a speaker and an amplifier, making her smarter, so she can perform new tasks, such as watching the news or changing the controls in the room.

There are also a significant number of frameworks created for the control and verification of household appliances. A home energy management system is part of a smart network that collects information from household appliances that use smart sensors.

In this paper [43], a home automation system with minimal effort and remote control is proposed (Fig. 7). The framework updates Android remote technology to provide remote access from a smart mobile. The design replaces existing electrical circuit breakers and provides more control over circuit breakers with low voltage triggering technology.

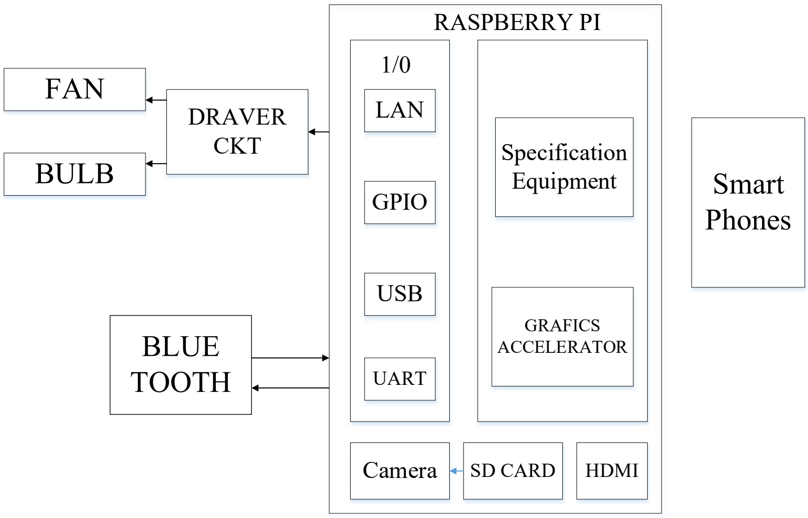

Fig. 7. A home automation system with minimal effort and remote control

The system uses a Raspberry Pi B+ single-board computer. The controller is connected to a web server on the Internet, receives the information needed by the user from any point. It is equipped with 4 USB ports, one ETHERNET port, memory card, router, speaker and HDMI interfaces.

The choice of a multi-sensor data fusion (MSDF) architecture is one of the key tasks in the design of a multi-sensor system. Three aspects of the MSDF architecture are considered: classification, optimal selection, and standardized presentation. In contrast to a yard of other works, the types of architecture are classified according to all three criteria, whereas previous works used only one or two. The optimal choice of MSDF architecture is a multi-objective optimization problem, and system simulation can be used as a standardized means of representing MSDF architectures [44]. The integration of several sensors into a system used to evaluate a phenomenon involves the use of MSDF methods [44]. A distributed multisensor system, as a rule, consists of several distributed probing nodes (sensors) and one or more processing nodes (processors), all interconnected. In sensors, key quantities describing the object are obtained from raw signals, forming an abstract representation of the potential object. In distributed multi-sensor systems, the MSDF architecture captures strategic decisions about the allocation of processing tasks to a set of distributed processors. The MSDF architecture consists of three components [44]: 1) communication graph (represents network communication between nodes, i.e., sensors and processors), 2) information graph (represents a detailed flow of information between interconnected nodes), 3) information content (determines what exactly is transmitted between nodes). A communication graph describes structure, while an information graph describes behavior.

Traditionally, the choice of the MSDF architecture is considered one of the key tasks in the design of a multisensor system [45]. MSDF has been used for a long time in systems with a small number of large sensors. However, the emergence of systems with a large number of (small) sensors, such as wireless sensor networks (WSN) or the Internet of Things (IoT), justifies the revision of the topic of MSDF architectures, given their strategic importance [45]. Therefore, it is appropriate to consider the classification of MSDF architectures, the optimal choice of MSDF architecture for a particular system, and a standardized representation of MSDF architectures. Given a set of classification criteria, there are a finite number of MSDF architecture classes. A single class can contain zero, one, or more types. If a class contains several types, it means that the types cannot be distinguished by the chosen set of classification criteria. A particular multisensor system uses a particular implementation of the MSDF architecture. Unlike types, implementations have a specified number of nodes (processors, sensors). An implementation implements a type and can even implement multiple types at different levels of the hierarchy [45].

The existing studies [46–50], which use different criteria(sets) of classification, which probably indicates that none of these studies have complete conclusions regarding the classification of MSDF architecture types. The papers made comparisons between MSDF architecture types or classes, but did not provide a commonly accepted framework for choosing an MSDF architecture implementation. The implementation of the MSDF architecture can be described using Systems Modeling Language (SysML).

Two classification criteria are considered in [38]. The first criterion (C1) is the place where the composition is processed. According to C1, track processing can be: 1) central level (observations are sent from sensors to remote processors to jointly form global tracks), 2) sensor level (local tracks formed by local processors attached to sensors are sent to remote processors that perform synthesis from a track to obtain global tracks), and 3) hybrid (a combination of central and local level processing). The second criterion is where the track file (database) is generated and maintained. According to C2, maintenance of track files can be: 1) centralized (a track file is maintained by a single central processor) and 2) distributed (a track file is maintained by several distributed processors). According to the third criterion (C3), the architecture can be: 1) singly connected (there is only one communication path from each sensor to each processor), and 2) multiple connected (there are several communication paths from at least one sensor to at least one processor).

Six types of architecture are considered in [47]: 1) central-level tracking with a centralized track file, 2) central-level tracking with a distributed track file, 3) sensor-level tracking with a centralized track file, 4) sensor-level tracking with a centralized track file and feedback, 5) sensor level tracking with distributed track file, and 6) hybrid.

Eight types of architecture are analyzed in [40]: 1) distributed tracking with responsibility for reporting, 2) composite tracking of a pure central level, 3) practical composite tracking of the central level, 4) distributed tracking with a central level of track merging, 5) distributed tracking with distributed track fusion, 6) distributed tracking with center-level track synthesis and trackets, 7) distributed tracking with distributed track fusion and trackets, and 8) distributed composite tracking.

Nine types of architecture are described in: 1) centralized, 2) disconnected, 3) replicated centralized, 4) hierarchical without feedback, 5) hierarchical with sensor sharing, 6) hierarchical with feedback by language, 7) peer-to-peer with neighbors, 8) broadcast and 9) cyclic. Four architectures are defined in [49]: 1) merging between tracks, 2) centralized tracking, 3) equivalent measurement architecture, and 4) local measurement of the track architecture. However, MSDF architectures are almost completely neglected now for IoT, but focusing on mathematical methods.

Data fusion models in intelligent monitoring systems

A significant number of works are devoted to the comparison of the monitoring system with existing commercial systems, as well as data analysis algorithms to improve their intelligence and synthesis or merging of data data, expansion of the current monitoring system to other areas of application. The model for levels of data fusion is presented in Fig. 8. Four levels of fusion are noted for measurement Level 0 (derivation of functions and patterns from source data and measurement data; Level 1 (determination of parametric and attributive states of the target entity); Level 2 (assessment of the situation of the business entity and its impact on related sub business entities); Level 3 (prediction of future impact based on the current situation).

Data fusion algorithms are proposed in [50]. To diversify their applications, there are different ways of classifying fusion algorithms. One approach is based on the level of abstraction, i.e., the signal level, the function level, and the decision level, and this is depicted in Fig. 8. Here the general application is shown and combined outputs are highlighted. At the signal level, the synthesis process provides more accurate data in terms of certain data quality metrics, such as signal-to-noise ratio. The combined result will be further processed for feature extraction and classification (identity declaration). Feature-level fusion is designed to obtain more discriminative features for other tasks. The solution takes symbolic representations as sources and combines them to obtain a more accurate solution [51].

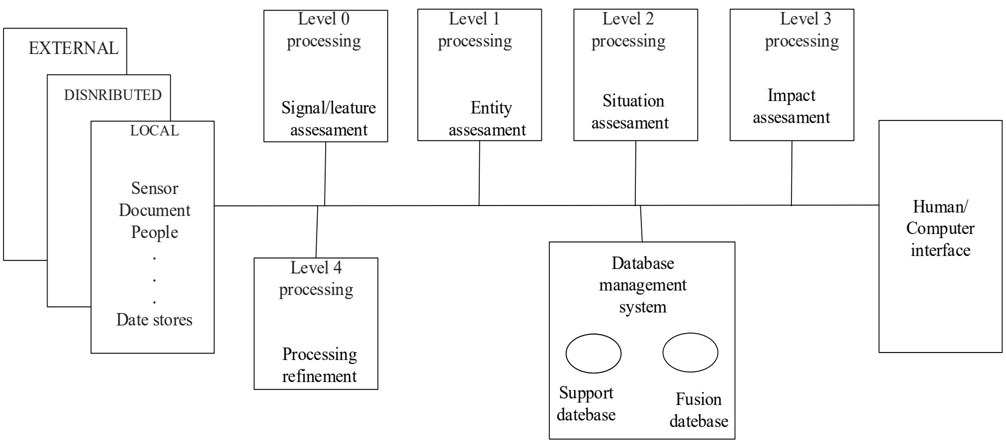

Fig. 8. Adapted unified data fusion model

Design of information and measurement system based on Raspberry Pi and sensor fusion architecture

Having analyzed the development of multi-sensor systems for monitoring and control of klamat, as well as possible data analysis algorithms, we proposed a two-level structure of a multi-sensor system that provides implementation with a distributed hardware architecture. This system consists of two units – Multi Sensor System (MSS), Coordinator Station (CC) and Central Control Station (CSC). The wireless network backbone is based on BLE modules for communication between the MSS and the End Device, while for communication between system elements, sensors, various types of cable interfaces are used, for example SPI, I2C, and other signal interfaces, and ADC elements are also used in the system, for presentation of information in convenient for transmission of data packets. Also, for the correct operation of the system, a stepper motor driver and a transistor are used as shown in (Fig. 9). The paper proposes a Raspberry Pi, a custom, fully adjustable and programmable PC board that has enough power to be used as a sensor hub. A multi-sensor BLE node installed on an intelligent device, which will be a multi-sensor module.

Having analyzed several functional modeling systems, we offer our own system. The method of calibrating this system will depend on the quality of the sensors. The sensors must be stable and the data must be processed within a short time after operation within the main cycle function. Fuzzy logic should ensure high accuracy of data acquisition. The process must establish communication from the medium range and send messages in a short period of time to the smartphone to report certain situations. This system can also be used for surveillance by changing the BLE module to a GSM module and changing some operators, especially the AT command.

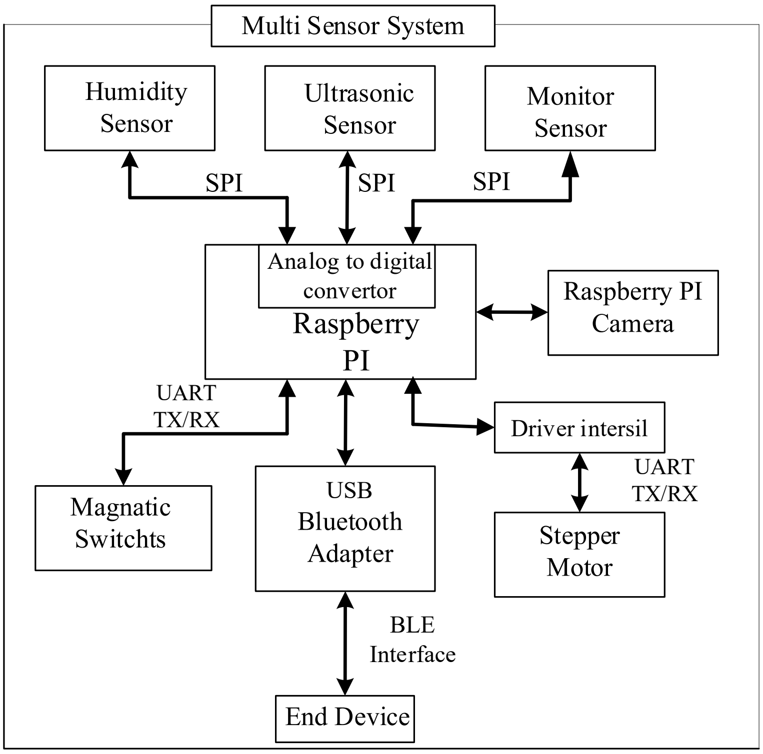

Fig. 9. Structural diagram of the information and measurement system with a multi-sensor configuration

Also, an important aspect is the development of a method for optimizing the spatial placement of elements of a multi-position multi-sensor system, taking into account certain characteristics. Recent advances in the Industrial Internet of Things enable the use of multiple sensors in an industrial environment for sensing, monitoring, and measurement. The need for understanding and useful information from sensory data drives the research and development of multisensory synthesis. Essentially, sensor data fusion can be modeled as the block depicted in Fig. 10(a). The three types of inputs include data/information sources, supporting information, and a priori external knowledge [51]. The output of the block is the merged results. Several fusion units can be arranged in parallel or in series, as shown in fig. 10(b) and fig. 10(c). In a parallel architecture, each fusion unit processes sensor data and passes the result to the next layer to combine the processed results from multiple sensors. In a sequential architecture, each fusion block receives input from the sensor and output from the previous block and passes the result to the next level block. Complex processing and joining algorithms are implemented in each welding installation. In addition, a hybrid scheme is possible, which includes both parallel and serial fusion architectures into a single system.

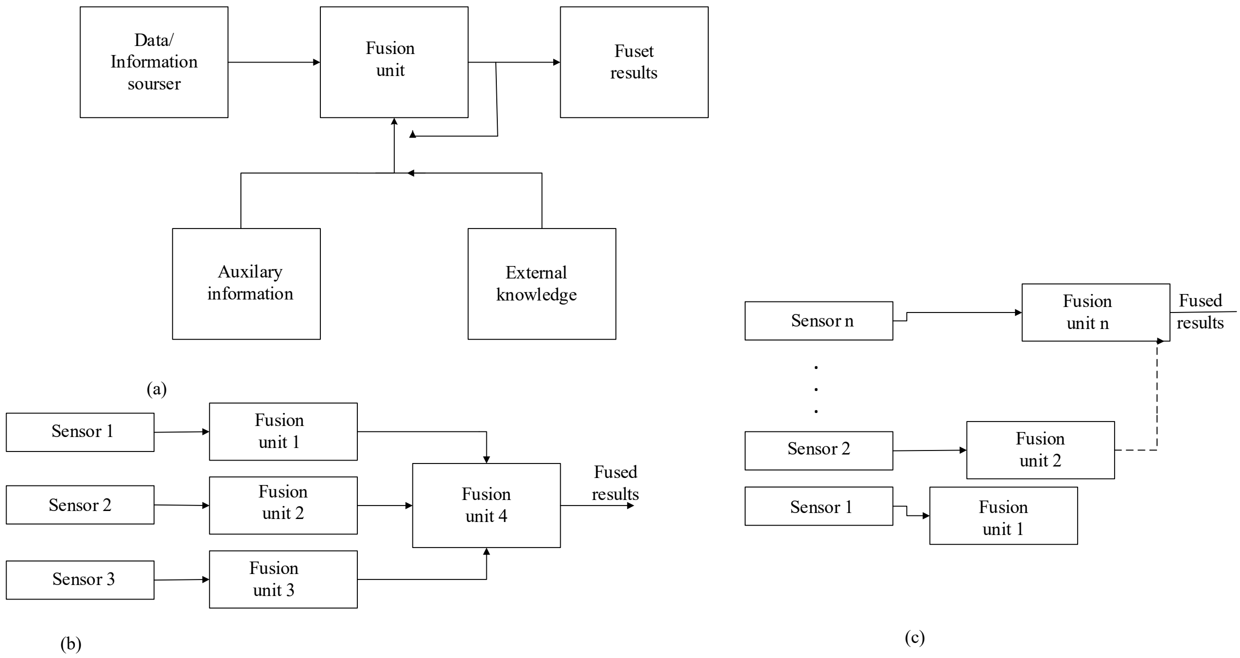

Fig. 10. Architecture sensor fusion block: one block (a), parallel arrangement of blocks (b), serial arrangement of blocks (c)

Conclusion

The analysis of literary sources (literature review) on the application of methods and means of intellectualization of information and measurement systems with a multi-sensor configuration is presented. Information-measuring systems perform the functions of control and coordination in the house – lighting, insulation, security, sound, blinds. In this situation, a smart home resembles an ecosystem that is controlled by a central "brain" and controlled by a smartphone. To control plant growth promotion parameters in the greenhouse, namely soil moisture, soil temperature, air temperature and humidity, carbon dioxide (CO_2) content and light intensity. Maintaining optimal levels of these environmental parameters is essential for healthy plant growth and maximizing fruit and flower yields. For home security control – on the move to a fire detection system, intrusion detection, using several technologies based on social networks. Also considered is the architecture of multisensory data fusion, which is one of the key tasks in the design of a multisensory system. With the emergence of systems with a large number of sensors, such as the Internet of Things, three aspects of the MSDF architecture are considered: classification, optimal selection, and standardized presentation. The analysis of literary sources provides an opportunity to improve the development of an information and measurement system with a multi-sensor configuration.

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