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# UNIVERSAL CONTROLLER FOR THE DISTRIBUTED MANAGEMENT IN THE ADAPTIVE SMART HOME SYSTEMS

It is developed the structure and algorithm of functioning of the universal controller of the adaptive smart home system. Distributed management provides increased survivability, and the modular principle of system organization ensures effective modernization in the future. The developed information model involves a connection with a remote data server using a Wi–Fi module on an ESP8266 microcontroller, which supports a local Wi–Fi network to provide control of a smart home through smartphones. A web page is associated with the local IP address of the ESP8266, through which users receive information on the current state of the home on their smartphone and can control it remotely. Periodically, through the same Wi–Fi module, the system sends data to the cloud server, as well as reads data from it for remote control of the home. The connection to the Internet is made through a Wi–Fi router. The system performs simple and urgent operations without the server involvement. Depending on the needs, the universal controller can be replaced with a specialized one. For efficient organization of the exchange of internal data between controllers, the protocol of two–wire shared bus I2C is used in the system. Communication between the system controller and the server is carried out via the universal UART channel. The system server transmits AT commands and data for the ESP8266 Wi–Fi module via the second UART channel. The proposed technical solution is characterized by a low price. The developed software for universal system controllers is developed in the assembly language for the STM8 microcontroller, which ensures high-speed operation of the device. Examples of the layout of the "transmitter" of the system and the implementation of the "receiver" of the adaptive smart home system are considered.

The hardware and software structure for controller development for distributed management in the adaptive smart home systems is proposed. The principles of intelligent adaptation of the system to the user were used to implement a smart home. The technical support of the adaptive system of the smart house is developed, which is characterized by a low price. The creation of such adaptive systems can be implemented with different "levels" of intelligence. During development, it is very important to maintain the maximum ratio: of quality as an approximate benefit in time, which saves the user of the system, to the cost of system implementation.

***Keywords:*** microcontroller, ESP8266, STM8, adaptive system, smart home.

## Introduction / Вступ

We live in a time of intelligent systems development in various fields of science and technology [1], [2], [3], which make it possible to significantly expand the functionality and improve the development of smart home devices [4], [5], [6]. However, on the one hand, the intelligent system of a smart home cannot always "understand" exactly what the user needs and the user cannot "explain" in detail to the system what exactly he needs. This happens because there is no common conceptual base between the intelligent system and the user. The principle of intelligent adaptation [7] is that the system "observes" the user for a certain time, forms a conceptual base, and then, when it finds a regularity in his actions, it begins to predict the course of his behavior and unobtrusively offer help options. Initially, such training principle was implemented to solve everyday problems faced by the user in the example of a smart home [3], [5], which allows the owner to increase comfort level and significantly reduce energy costs. In order, to implement the specified approach, it is necessary to equip the house with appropriate technical support, namely: microcontrollers, a system of sensors, executive devices, and data analysis tools that will help to form a conceptual base based on the events, recorded by sensors, and the corresponding actions that the user performs at home. On the other hand, the implementation of an adaptive system requires the development of special software, which should process the received data in real-time and be based on intelligent methods, models and algorithms.

Accordingly, the development of methods, models, software and hardware of the controller of the adaptive system of a smart home is *an urgent task*.

*The object of research* – the process of collection and preliminary processing of input data for smart home system controller development.

*The subject of research* – a method of developing a controller for distributed management in the adaptive smart home system.

*The purpose of the research* – to develop the controller of adaptive smart home system for collection and preliminary processing of input data.

To achieve this purpose, the following *main research tasks* are identified:

– to develop the structure of an adaptive system of a smart home, which is based on the modular principle;

– to design the structure and algorithm of the controller of the adaptive system of the smart home, which is based on the modular principle, which makes it possible to quickly modify it during the development of the system;

– to develop the technical support of the controller of the smart home adaptive system, which is characterized by a low price;

– to create the software of the controller of the adaptive system of the smart home, which makes it possible to ensure the high speed of the designed system.

***Materials and methods of research.*** The work uses data preprocessing methods, modern methods and algorithms for building intelligent control systems, client-server organization, modern components and an elemental base for the implementation of hardware and software components, and intelligent processing from sensors.

***Analysis of recent research and publications.*** Today, the class of smart home systems [8] (or in other words "intelligent" home systems) arouses the interest of researchers, scientists, developers and designers of complex systems, even considering that such systems have been developed since the 50 s of the last century. However, today smart home systems are fundamentally different from their early versions [9], mainly due to constant changes and growing requirements for such systems, as well as for technologies, methods and means of their design, development, implementation and exploitation. The modern client wants to get from such system maximum comfort of use, maximum adaptability and maximum autonomy. The system must take into account user behavior, constantly monitoring where the user is at the moment, what exactly he did and what the user will do shortly. At the same time, the system should be "invisible" to the user as much as possible.

The introduction of smart home systems (SHSs) that meet all modern requirements, needs the development of new or improvement of existing methods and means of design [10], modeling and research of SHSs. The works [7], [11] reveal the development of specific SHS models based on Petri–Markov networks and supplemented with functional components – sensors and actuators. The adaptability of smart home systems and their personalization is considered in [12]. The research of the behavior of smart home users is analyzed in [13], and the use of ANNs to implement this process is considered in the work [14]. The authors of article [15] proposed a model of the relationship between a person and a system for implementation in a smart home system. This model divides the smart home into a set of intelligence levels to better manage the intelligent development of the smart home industry. To test this approach, an experimental environment has been built for assessing the intelligence level of a smart home system. In the work [16] it is proposed to apply deep learning to the classification of Internet of Things (IoT) data, aimed at a smart home, and to detect human activities using environmental sensors. The article [17] describes an automation system that can be controlled by gestures. The use of sensors in smart homes is summarized in the work [18] and several gas leak detection methods using IoT, Bluetooth, and Wireless Sensor Network (WSN) are compared, and technical challenges are discussed. Human activity recognition (HAR) is an important part of a smart home. The authors in [19] emphasize that it is always better to build a HAR model for each smart home to solve the problem of different floor plans or used sensors. The authors propose a method to transfer the HAR model from several defined source homes to the target home.

In [20] the authors investigated the cost of deploying sensors and their expected accuracy in a house with 2–5 residents. Research [21] focuses on the analysis of sensor networks for smart home user recognition, where the system structure is divided into three levels awareness, situational management and situational application. At the same time, a complete and practical information model is defined. An approach to detecting anomalies in smart grid systems is presented in [22], where the functionality of the sensor system is checked using machine learning.

Human activity recognition in smart homes is considered in [23], which is based on machine learning methods to detect future activities. In the paper [24] the authors combine BLE and sensors to apply indoor systems of localization for smart homes to prevent energy waste. The analysis of people's mobility models is considered in the article [25], which is made to identify people's behavior and to provide appropriate services for different groups of residents of buildings.

The use of IoT-based solutions to build a smart home is widely discussed. In work [26] a smart home is considered, where the measured sensor data are transmitted to the cloud server IoT ThingSpeak, and a system for condition analysis is proposed. In the work [27] the proposed project is a cost-effective IoT-based home automation system for home monitoring and control with a convenient interface. The article [28] presents a smart home system for real-time data collection using IoT cloud technologies in VANET implementation

Various types of sensors can be used to implement smart home functions. The types of sensors for smart home and related smart home services are classified and analyzed in the article [29]. The authors in [30] propose an adaptive sensor data transmission planning scheme aimed at reducing the size of the transmitted data by classifying and excluding unnecessary data. The work [31] analyzed various types of sensors for smart homes and described their parameters. The authors in [32] considered the design of a smart home solution ESP8266 NodeMCU with the implementation of the MQTT protocol. In [33] it is discussed the design of control systems for smart home circuits with different groups of controllers. The paper [34] presents the design and implementation of an Arduino–based smart home, where some predefined actions can be performed to prevent resource wastage.

Therefore, the development and implementation of SHS, in which the user wants to get maximum comfort through adaptability and autonomy of functioning, remains an actual task. The analysis shows that today there is a wide discussion of SHS tools to account for behavior of users and adapting to their behavior. At the same time, the system must be equipped with appropriate sensors and ensured with communication tools, mainly based on IoT.

## Research results and their discussion / Результати дослідження та їх обговорення

The developed adaptive structure of the smart home system includes four main components (Fig. 1). The first component is the controller, which is designed to collect and preliminary processing data about the owner of the premises or group of residents, namely: identification of the person, location, time, identification of the owner's actions, etc. The second component is the database (DB) and knowledge base (KB), which store data and knowledge obtained from the controller and in the process of functioning the adaptive smart home system in general. It should be noted that knowledge are formed on the basis of the analysis and processing of data from the controller. The third component is a module for processing input data, information from the database, and knowledge base, which uses methods and models based on the Petri–Markov theory [7], [11] and generates control signals to the subsystem of executing devices (actuators). The fourth component is directly executive devices. The proposed structure of the adaptive smart home system uses a client-server organization. The system includes the controller of the adaptive system of the smart home (CASSH).

The structure of CASSH is shown in Fig. 2. Information gathering from sensors and data transmission were performed on STM8 microcontrollers [35]. Data communication between controllers is implemented using the $I^2C$ protocol. The system is connected to the Internet using the ESR8266 SoC microcontroller.

The connection scheme of executive devices and sensors of CASSH is shown in Fig. 3.

For example, if we consider a two-room house, accordingly, in each of the rooms there should be a receiver of infrared signals and an analyzer built on the basis of an STM8 microcontroller. All "receivers" are connected to each other by a common bus and connected to the "host" (the main microcontroller), which polls the "receivers" at certain intervals about the presence of a resident in its area of operation. The "host", which is also developed on the basis of an STM8 microcontroller, is connected to the ESP8266 WiFi module, which in turn transmits the received data to a remote server for further processing. The owner of the premises must wear a "sensor" in the form of a badge, which can be attached to any clothing and is constantly in an active state, powered by a battery.

The resident's behavior control system is implemented on the basis of infrared radiation. It is not noticeable to the owner and is not harmful to him and his surroundings. Thanks to a large number of infrared sensors, the system accurately determines the location of a person in the room. In addition, the badge provides additional information on the position of the user's body to more accurately determine the situation in which he is.

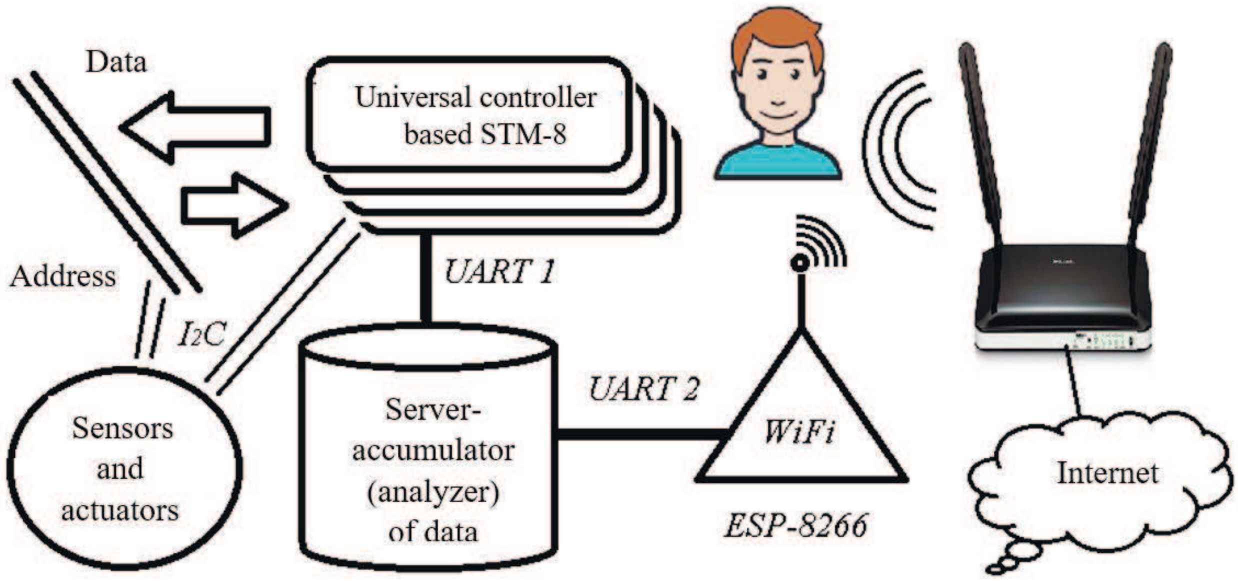


**Fig. 1.** General structure of an adaptive smart home system / Загальна структура адаптивної системи розумного будинку

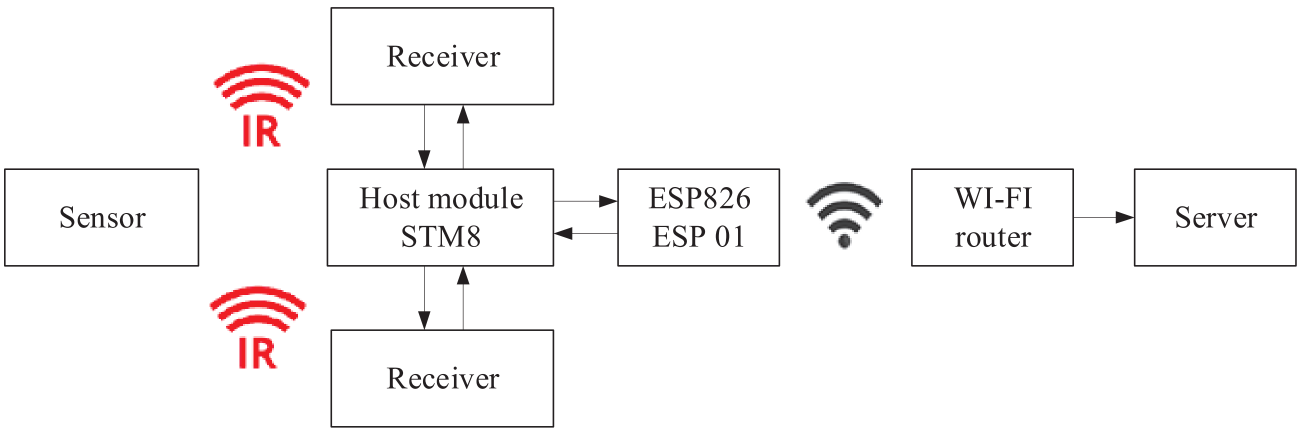


**Fig. 2.** Simplified structural diagram of CASSH / Спрощена структурна схема CASSH

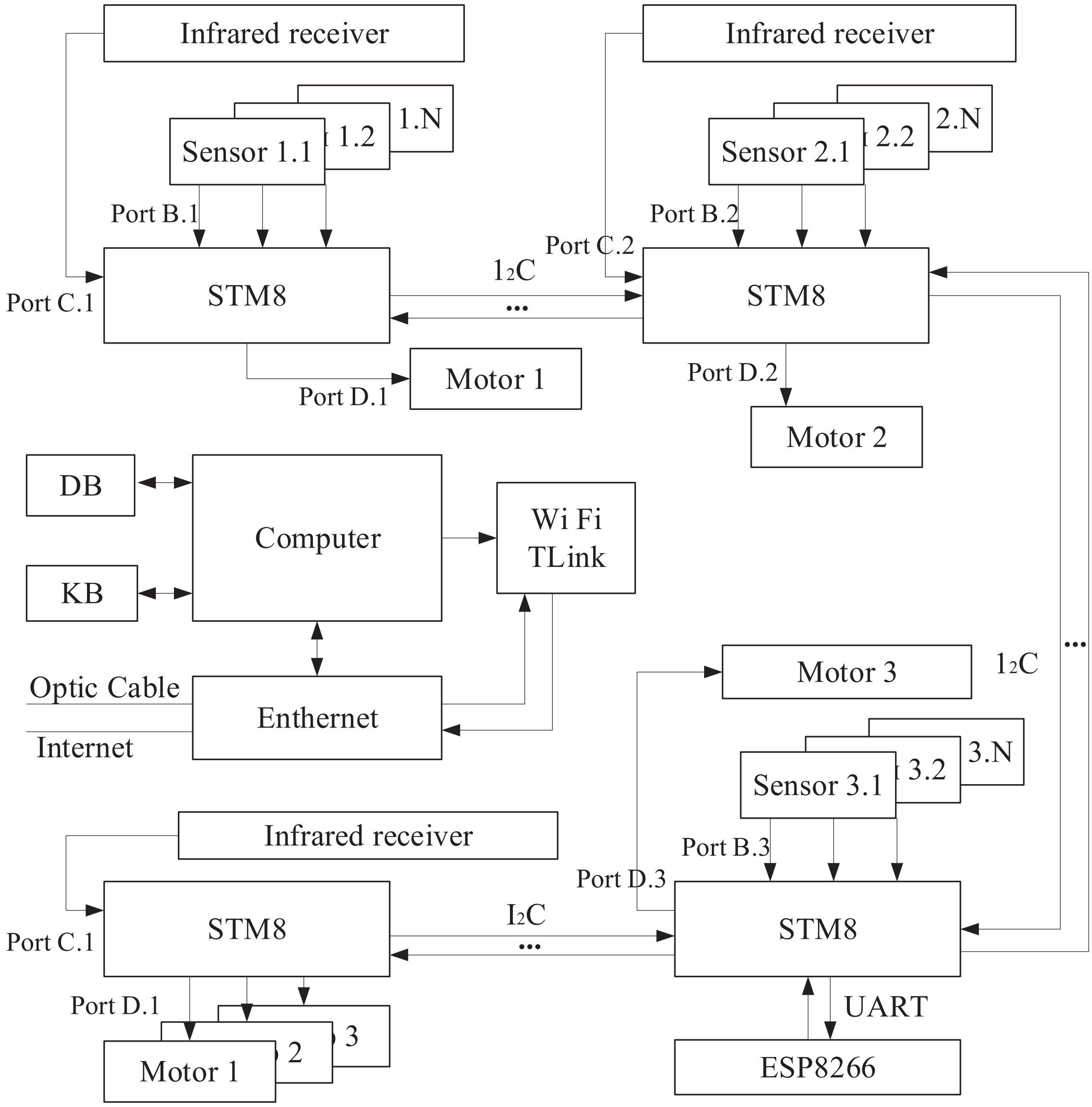


**Fig. 3.** Connection diagram of executive devices and sensors of CASSH / Схема під’єднання виконавчих пристроїв і сенсорів CASSH

The modules are equipped with high-quality infrared devices. Accordingly, the “receiver” is equipped with an infrared receiver module TSOP38238, and the “sensor” is equipped with an infrared LED L-53F3C.

CASSH functions according to the developed algorithm. In general, the algorithm of the controller involves the following main steps (Fig. 4):

Step 1. Initialization of the system.

Step 2. If the system is not ready for operation, then go to step 1. Otherwise, go to Step 3.

Step 3. Alternate survey of all system controllers.

Step 4. There is no useful information from the system controllers – go to Step 3. Otherwise – Step 5.

Step 5. Preliminary processing of the received useful information from the controllers.

Step 6. Saving useful information in the database.

Step 7. Sending a sequence of control signals to executive devices.

Step 8. Shut down the system, if the corresponding command is received, go to Step 8. Otherwise, go to Step 3.

Step 9. System preparation and completion.

***Development of technical support for the controller of the adaptive smart home system.*** The basis of the development of hardware and software systems is the choice of means of the system’s reaction to an external event in order to achieve the set goal. Events are single-valued, when a certain event leads to only one logical conclusion about the choice of reaction to it, or multivalued, when after the occurrence of an event it is impossible to make a specific conclusion, but it is possible to reject some set of false conclusions, if the logic of the system’s functioning is used. Let’s give an example.

Suppose, that the state of the microcontroller leg was changed, to which the infrared receiver is connected. It follows from this event that an information code is transmitted to the system, which must be determined. The code can be a forced command from the remote control or the activation of a class of actions that are associated with the presence of a badge of a certain resident of a smart home.

In order, to receive the information code, it is necessary:

1. Interrupt the execution of the current algorithm and switch to the subprogram – the interrupt handler from this leg.

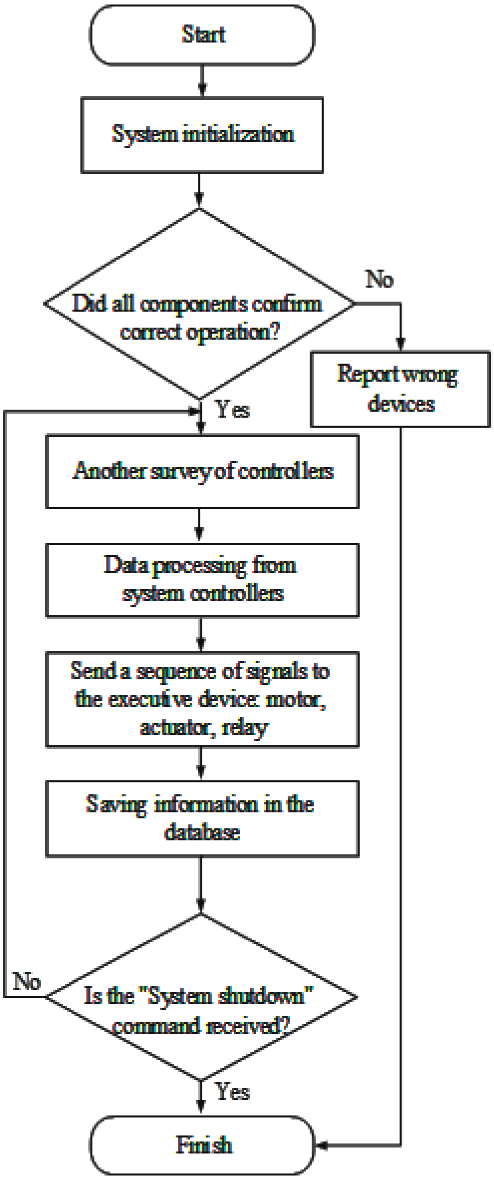


**Fig 4.** Block diagram of the CASSH work algorithm / Структурна схема алгоритму роботи CASSH

2. If this pulse is the first, that is, changes have not occurred for a long time (the working timer was full), then it is necessary to clear the data array for receiving the code, reset the value of the working timer to zero and return to the interrupted program to continue its execution.

3. If this is not the first pulse, and the number of transmitted pulses is less than the specified one, then write the current value of the working timer into the array, reset this timer and return to the interrupted program.

4. If the number of pulses is greater than the specified number, then prohibit the interruption from this leg, analyze the code received in the array, perform the corresponding action, then allow the interruption again and return to the interrupted program.

5. If the code does not match any of the allowed codes, send an error message to the host (data hub).

This was a basic example that demonstrated the general logic of interrupt-based hardware and software functioning.

There are parametric and structural adaptations. Parametric adaptation algorithms find optimal values of critical parameters, based on which the system makes decisions. Structural adaptation begins with the replacement of individual blocks of the system with more beneficial ones from the point of view of the general goal, and ends with a complete search of all possible structures of the system to find the connection of the structure with the specified purpose of functioning.

Before starting development, it is necessary to compile a table of all possible states that the system can go into. In theory, this table will be large enough and can be supplemented over time, especially if we take into account intentional damage, falsification of data for the purpose of deception, children's games, pets, inappropriate neighbors, unlikely natural phenomena, etc. One system state differs from another by a set of characteristic features that can be obtained by analyzing the sensors' indicators. The response of the system should not be 100 %, but "weighted", considering that there may be an unknown influence that requires more careful study. Therefore, the system includes a concentrator and a data interpreter, on the basis of which further adaptation of the system will take place.

The analysis is based on the method of interpreting the data received from the sensors as the occurrence of one of the states presented in the table of the possible list. From a mathematical point of view, this is a problem of clustering and recognition. Algorithms of the system's adaptive response to external events are in the process of testing. This approach is new and does not guarantee universality.

It is proposed the following hardware and software structure (Fig. 5).

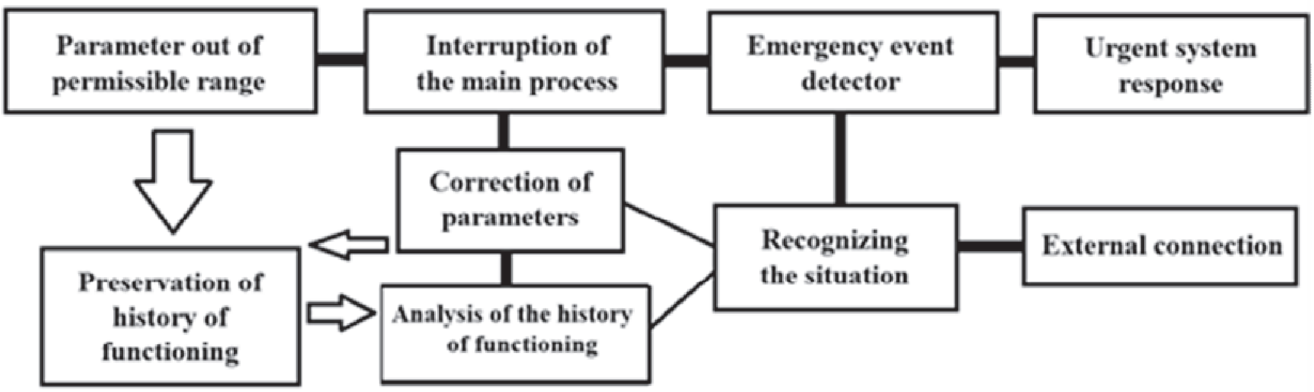


**Fig. 5.** Structure of hardware and software / Структура апаратно-програмного забезпечення

The ESP8266 wireless microcontroller has a built-in Wi–Fi module that allows the microcontrollers of created system to access the Wi–Fi network. This microcontroller is a self–contained SoC (System on Chip) and provides input and output control. Depending on the version of the implementation of a particular module on the ESP8266, it is possible to have up to 9 GPIO. This makes the ESP8266 versatile for use in smart home projects.

An infrared LED is connected to the board based on the STM8S103F3P6 microcontroller to implement the "sensor". A lithium battery is used to ensure uninterrupted operation. To implement the "receiver", a TSOP38238 infrared receiver is connected to a similar board. Two such "receivers" were implemented to build the system layout. The example of the layout of the "transmitter" of the adaptive smart home system is shown in Fig. 6. The example of the implementation of the "receiver" of the adaptive smart home system is shown in Fig. 7.

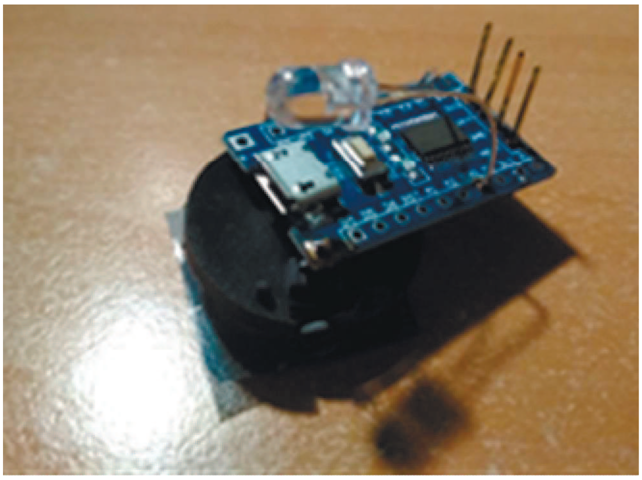

**Fig. 6.** An example of the layout of the implementation of the "sensor" of the adaptive smart home system / Приклад макета реалізації "сенсора" адаптивної системи розумного будинку

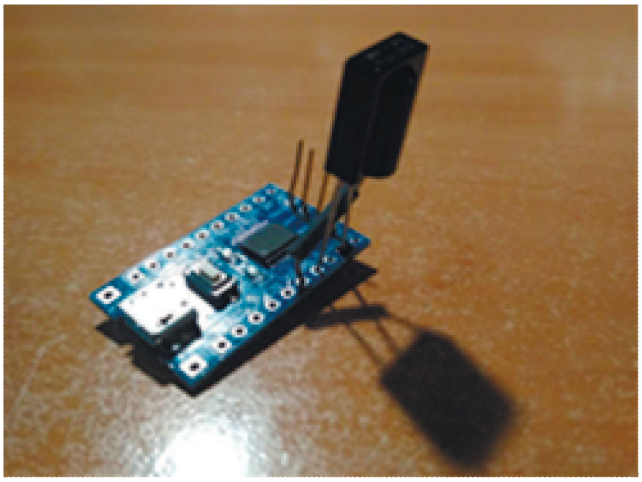

**Fig. 7.** An example of implementation of "receiver" of an adaptive smart home system / Приклад реалізації "приймача" адаптивної системи розумного будинку

Therefore, the developed technical support of CASSH is characterized by a low price and wide functionality, which is due to the use of microcontrollers.

To implement the "host", the ESP8266 ESP01 Wi–Fi module was connected to the STM8S103F3P6 board.

To implement a complete system, all devices are connected by a common bus which transmits data using the $I^2C$ protocol (Fig. 9).

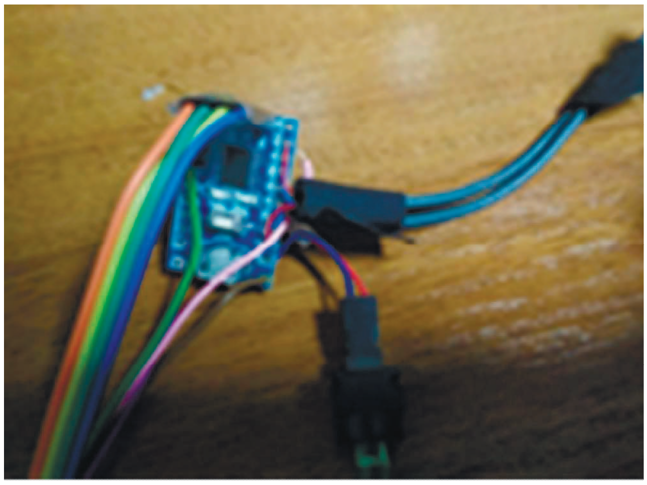

**Fig. 8.** Implementation of the "host" / Реалізація "хоста"

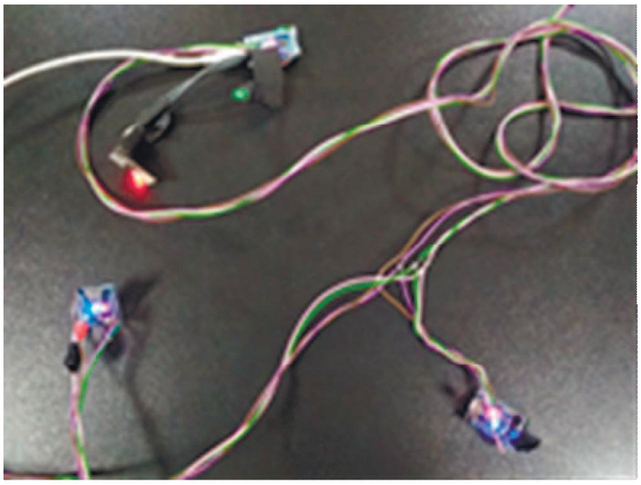

**Fig. 9.** Implementation of the system / Реалізація системи

***Features of the software development of the controller of the smart home additive system.*** Developed software for CASSH. The software was developed in the ST Visual Develop environment [41]. A special ST-Link V2 mini programmer was used for programming STM8 microcontrollers. The programs are implemented using AT commands and the assembly programming language for STM8 microcontrollers.

To implement the functioning of the "sensor", a study of the module parameters was carried out. The resonant frequency of the transmitter was determined using an elementary algorithm that changes the duration of the pulses. After several experiments, the resonant frequency was determined with pulse durations of 7, 14 and 15 units.

Implementation of the $I^2C$ protocol for the "host" is shown in Fig. 10.

Implementation of the $I^2C$ protocol for the "receiver" is shown in Fig. 11.

The developed software using the STM8 assembler ensures high speed of the controller. The software for the Wi–Fi module ESP8266 type ESP-01 was developed in the Arduino IDE environment and has no special implementation features.

*Scientific novelty of the obtained research results* – the development of adaptive system, which is discussed in this work, differs from classic hardware and software solutions. The very principle of adaptation determines that the system changes in the process of functioning to improve its work.

*Practical significance of the research results* – the principles of intelligent adaptation of the system to the user's behavior are used in the implementation of smart home tools. The developed structure of the adaptive system and the smart home controller are based on the modular principle, which allows for their rapid improvement in the future.

## Conclusions / Висновки

The structure of the adaptive system and the controller of the smart home were developed, which are based on the modular principle. It makes it possible to quickly and efficiently modernize the designed device.

It was built the algorithm of functioning of the adaptive system of the smart home. It was developed the technical support of the adaptive system of the smart house, which is characterized by a low price.

It was developed the technical support of the controller of the adaptive system of the smart home, which is based on the use of the STM8 microcontroller. It ensures a low price of the device and the possibility of changing the functionality of the microcontroller.

It was developed the software of the adaptive smart home system, which is implemented on the STM8 microcontroller by assembly language, which ensures the high speed of the functioning of the device.

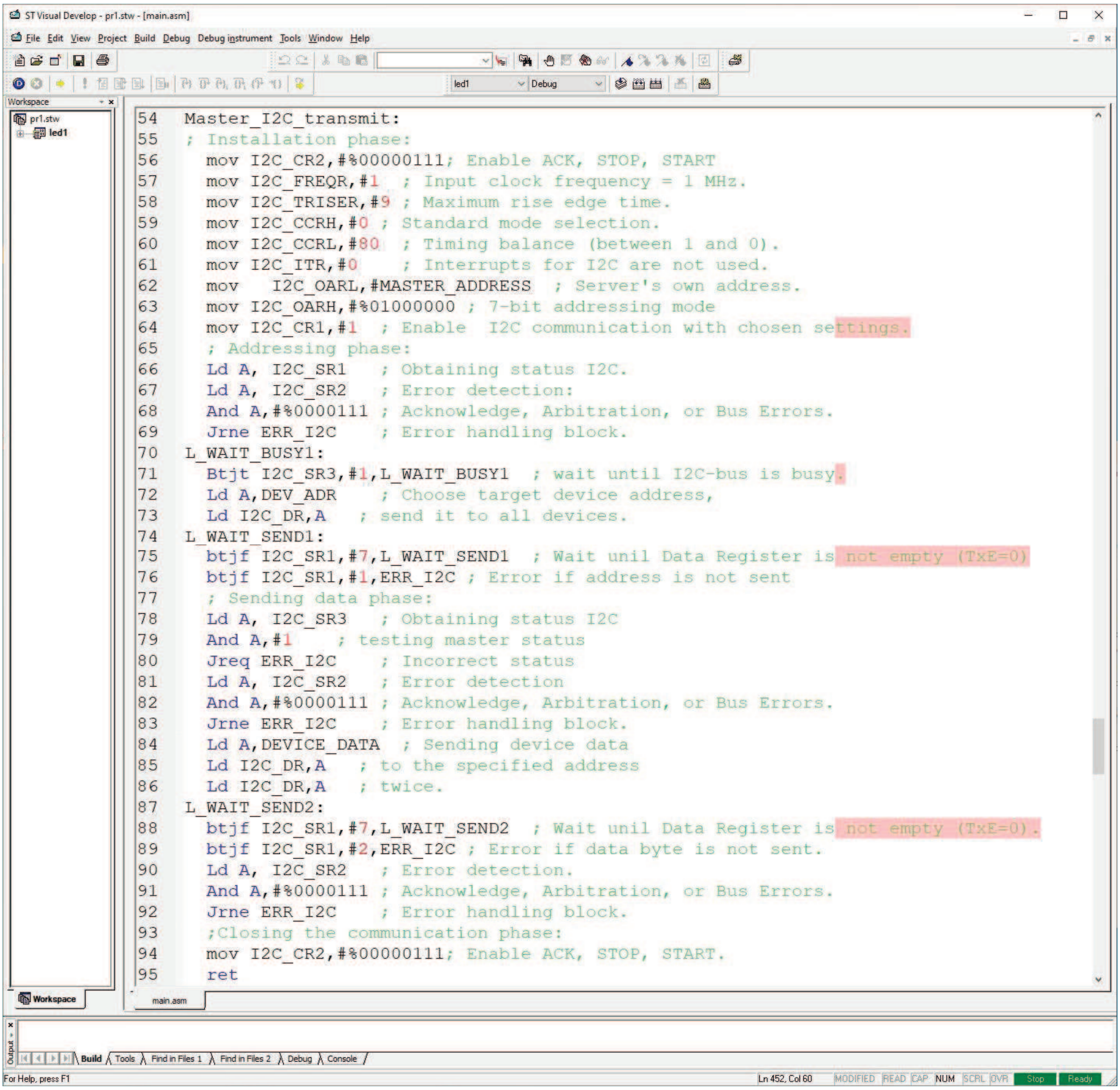


**Fig. 10.** A fragment of the I²C protocol implementation code for the "host" / Фрагмент коду реалізації протоколу I²C для "хоста"

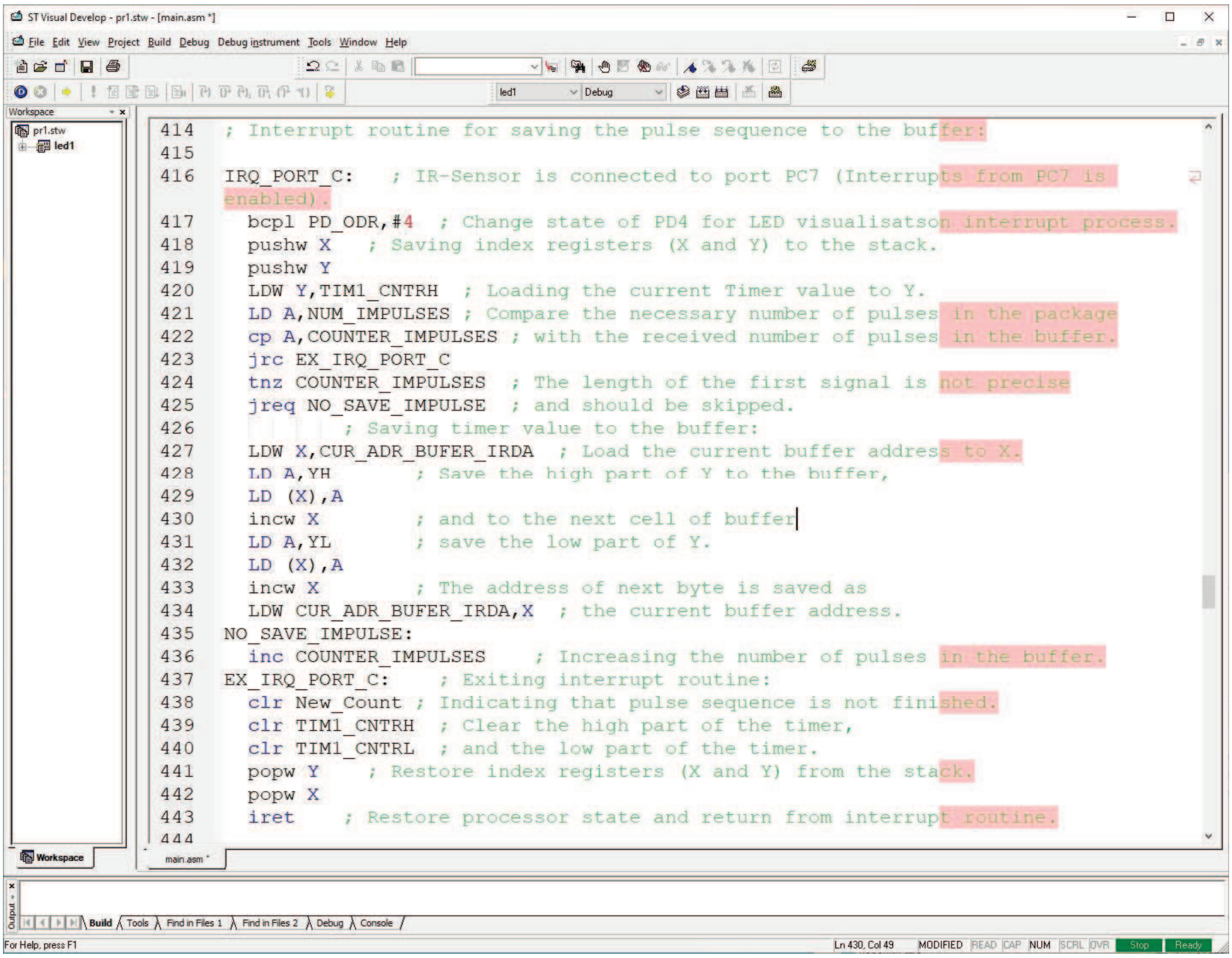


**Fig. 11.** Part of the I²C protocol implementation code for the "receiver" / Частина коду реалізації протоколу I²C для "приймача"

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# УНІВЕРСАЛЬНИЙ КОНТРОЛЕР ДЛЯ РОЗПОДІЛЕНОГО КЕРУВАННЯ В АДАПТИВНИХ СИСТЕМАХ РОЗУМНОГО ДОМУ

Розроблено структуру та алгоритм функціонування універсального контролера адаптивної системи "розумний дім". Розподілене управління забезпечує підвищену живучість, а модульний принцип організації системи – ефективну модернізацію у майбутньому. Розроблена інформаційна модель передбачає зв'язок із віддаленим сервером даних за допомогою Wi–Fi-модуля на мікроконтролері ESP8266, який підтримує локальну Wi–Fi-мережу для забезпечення управління "розумним будинком" через смартфони. З локальною IP-адресою ESP8266 пов'язана вебсторінка, через яку користувачі отримують інформацію на смартфон про поточний стан будинку і можуть дистанційно керувати ним. Періодично через цей самий Wi–Fi-модуль система відправляє дані на хмарний сервер, а також зчитує з нього дані для дистанційного управління будинком. Підключення до Інтернету здійснюється через Wi–Fi роутер. Для ефективної організації обміну внутрішніми даними між контролерами в системі використано протокол двопровідної спільної шини $I^2C$. Зв'язок між системним контролером і сервером здійснюється через універсальний канал UART. Сервер системи передає AT-команди та дані для модуля Wi–Fi ESP8266 через другий канал UART. Ціна пропонованого технічного рішення невисока. Програмне забезпечення універсальних системних контролерів розроблено на мові асемблера для мікроконтролера STM8, що дає змогу забезпечити високу швидкість роботи пристрою. Для реалізації "розумного дому" використано принципи інтелектуальної адаптації системи під користувача. Розроблено технічну підтримку адаптивної системи розумного будинку, яка характеризується невисокою ціною. Під час розроблення враховано збереження максимально ефективного співвідношення: якість як вигода в часі до вартості впровадження системи.

***Ключові слова:*** мікроконтролер, ESP8266, STM8, адаптивна система, розумний дім.

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