Development of the indoor climate control system

Sergey Polesskiy
School of Computer Engineering
National Research University
Higher School of Economics
Moscow, Russia
spolessky@hse.ru

Daniel Klyuvakov
School of Computer Engineering
National Research University
Higher School of Economics
Moscow, Russia
ddklyuvakov@edu.hse.ru

Alexander Tonkov
School of Computer Engineering
National Research University
Higher School of Economics
Moscow, Russia
astonkov@edu.hse.ru

***Abstract*—Nowadays smart home technologies are developing rapidly. Much attention is paid to the issues of intelligent control of microclimate parameters in residential buildings. The article examines the existing approaches to microclimate control, presents the methodology and results of designing the microclimate control system. The system monitors and regulates temperature, air humidity, carbon dioxide concentration in the room autonomously or in the mode of scenarios set by a user. Ventilation adjustment is based on a number of people determined by computer vision algorithms. Ventilation is provided by software-controlled supply valves and an extract fan. A key feature of the system is the ability to add additional climate control devices (for example, a heater, air conditioner or air humidifier) as part of the Smart Home concept (concept of use of electronics to complete various household tasks with minimal human interaction).**

Keywords—smart home, internet of things, computer vision, microclimate control, STM32, microcontroller systems.

I. INTRODUCTION

It is necessary to take into account adaptability of new product within the “Smart Home” system [1] to other devices, relevance, significance for the consumer. Nowadays there are many solutions for the automation of lighting [2], for the creation of monitoring systems to track the readings of devices in the house on the market. The microclimate and ventilation control system in particular occupies a special place in a smart home, because it directly affects the health of residents. The possibility of integrating ventilation into the “Smart Home” system expand the variations in monitoring the state of the indoor microclimate and improve it’s quality. An analysis of existing solutions and approaches was carried out before starting the design of an intelligent microclimate control system.

A. Supply valve

The simplest option is installing a supply valve with a foam rubber filter either in the frame of the window system or under the windowsill. The advantages of this solution are easy installation and operation, delivery of air filtered from coarse dust to the room. The disadvantages are the need for human participation in the regulation of air flows, the lack of control of the amount of supplied air. A separate supply valve cannot be integrated into the Smart Home system without modification.

B. Air recovery systems

The next solution is the installation of air recovery systems [3, 4]. The operation of such systems is based on the simultaneous flow of fresh air from the street into the room through the supply valve, and the exhaust air from the room to the outside through the fan through separate channels. In summer, the supply air is cooled, in winter it heats up. Thus, the change in the state of the microclimate in the room is carried out by a directed air flow. Air recovery valve is shown in Fig. 1.

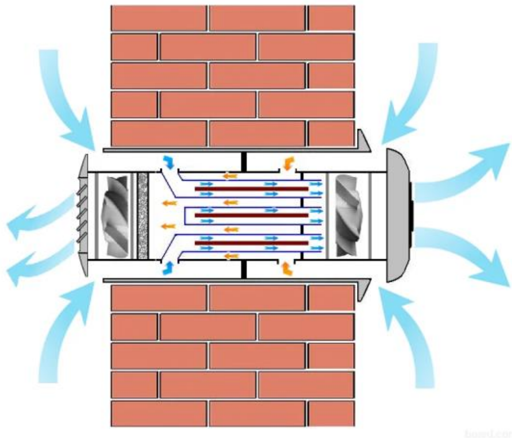

Fig. *1*. Air recovery valve.

The benefits of such systems include ease of installation and operation, relative cheapness, the possibility of simultaneous inflow and exhaust of air. The drawbacks are a high noise level, a narrow range of control modes (as a rule, three performance modes, set via an infrared remote control). This device is more applicable in Smart Home systems, but even a small noise of it can affect the sleep of residents at night, and later on, health [5, 6].

C. Supply and exhaust ventilation

The another solution is supply and exhaust ventilation [7, 8]. The action is based on the use of two pipe channels: through one, fresh air from the street is delivered to the room, through the other, exhaust air is extracted into a common ventilation shaft, or into the street (see Fig. 2).

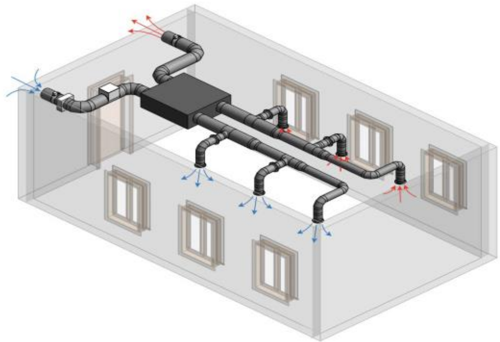

Fig. *2*. Supply and exhaust ventilation.

The advantages include a high degree of ventilation quality and productivity. The disadvantages are the high cost, the complexity of the installation (pipes take up a lot of space

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above the ceiling), the ability to install only at the repair stage. Typically, such solutions are used in industrial or office premises.

D. *Compact supply and exhaust system*

Such systems are designed for apartments and houses where the installation of bulky pipes is difficult. The principle of operation is similar to the previous solution: fresh air enters the room through a supply valve installed in the wall. The exhaust air is discharged through a standard house hood. The benefits of the solution are the possibility of intelligent control, compactness, ease of installation and operation [9]. The drawbacks are the relatively high price of the kit and additional modules.

II. PROBLEM STATEMENT

It is necessary to design a system of monitoring and controlling the microclimate parameters in a room both autonomously and in the mode of scenarios set by the user, explore the possibility of using it as the core of the Smart Home system, to which it is possible to add additional microclimate control devices such as a humidifier, heater, air conditioner, investigate application of computer vision within the framework of the integration of the microclimate control system into the Smart Home system.

III. METHODIQUE DESCRIPTION

A. *System architecture*

The climate control system is a fully controlled, automatically adjustable supply and exhaust ventilation system. The system architecture is shown in Fig. 3.

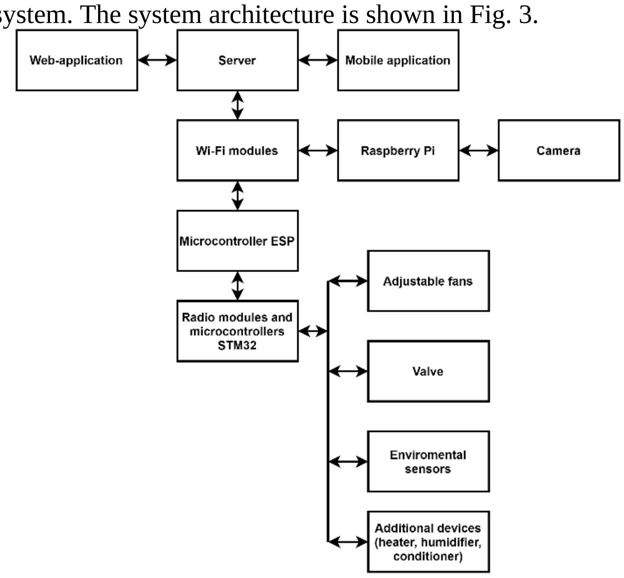

Fig. *3*. System architecture.

The architecture is a large network of devices throughout the home. The main microcontroller is complemented by small computing devices in all rooms to receive readings from a variety of sensors. An extensive device system allows to increase the number of executable and reading devices. Additional elements of the system can be installed in the room and connected to existing controllers. For example, smart lighting devices can be easily integrated into an existing system. It is necessary to add the necessary sensors, connect them to the existing controllers, and also add an electrically controlled relay to the light source.

The user, through a mobile or web application, can monitor and change several parameters of the indoor air: carbon dioxide content, humidity, temperature (See Fig. 3). A desired data is transferred to the controller, which activates the executable devices - fan and wall valves. The interaction of the fan and valves allows to adjust the air exchange in the room, which is required at the current time. Measuring environmental sensors continuously monitor the microclimate parameters. An important feature is the ability to create scripts for the system. Script is an algorithm by which the system will automatically work based on user-specified parameters. For example, every morning before user's waking up, the room temperature can be set to 18 ° C. This principle of operation allows to adjust a comfortable indoor climate for each person, depending on his preferences.

B. *Microcontroller*

The microcontroller is one of the key components in building a system. Microcontroller functionality:

- Collection and analysis of data from measuring sensors.
- Making decisions on the activation of various actuators based on data analysis.
- Data exchange with the server to output information to the mobile and web applications.
- Receiving data from the server and monitoring the maintenance of microclimate indicators.

An STM32 based controller was chosen as the main controller as a result of market research [10]. In terms of characteristics and price, this controller is significantly superior to the popular Arduino controller [11]. The controller works according to the following algorithm:

- Carry out a poll of all measuring devices by means of the NRF24l01 + radio modules.
- Process the received values and send them to the server for further demonstration to the user.
- Receive data from the server to process the desired script specified by the user.
- Compare the values of the parameters in the script with the current values from the sensors.
- Send commands to executive devices to adjust current indicators.

C. *Air flow sensor*

It is necessary to analyze the market of available air flow sensors and choose the best one for the correct functioning of the developed supply and exhaust system. This sensor allow to measure the speed of the supply and extract air, which is necessary for the correct calculation of air exchange in the room per person per hour. The calculation of air exchange is carried out in accordance with the expression (1):

$$Q = V \cdot 3600 \cdot \pi \cdot R^2 \quad (1)$$

where Q stands for air consumption, m^3/ hour; V for speed of air flow through the sensor, m/ s; 3600 for time, s; R for pipe radius, m.

This sensor is located in a pipe that is installed in a wall in a specific room. At the end of the pipe there is a valve, which regulates the amount of air entering the room from the street by means of a stepper motor. An analysis of existing solutions shows that there are several main types of sensors for air flow velocity:

- Vane anemometers.
- Pitot tube.
- Thermoanemometers.
- Ultrasonic meters.
- Laser meters.

Hot-wire sensors are the most suitable for the required price and placement conditions. They are small in size, have a large measuring range, and can be completely controlled by an electrical circuit.

This type of sensor (diagram is shown in Fig. 4) works on the principle of heat exchange between the sensor and the environment. An increase in the air flow rate leads to an increase in the thermal energy loss of the heating resistor. The heating resistor is cooled, which changes the heat transfer coefficient. Therefore, knowing the cooling coefficient of the heating resistor, it is possible to derive a function of the air velocity in the environment.

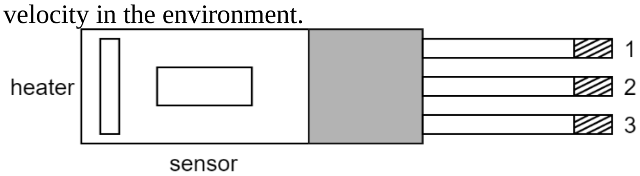

Fig. 4. Air flow sensor scheme.

By adjusting the input voltage at the sensor, it is possible to maintain a constant temperature difference between the heating element and the temperature sensor. The temperature difference must be converted into a function of the flow rate. Thus, the power is converted to voltage and the output from the bridge circuit (see Fig. 5) can be read by the microcontroller.

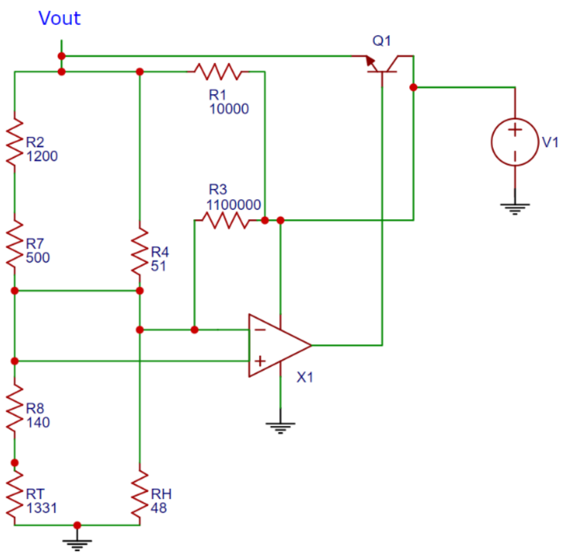

Fig. 5. Air flow sensor circuit diagram.

The 10V power source supplies voltage to the collector of the BC635 transistor and the power input of the LM358 operational amplifier. The transistor opens from the voltage from the output of the operational amplifier. Resistor RT - temperature sensor in the flow sensor. Resistor RH is a heating resistor. Both resistors are connected to different inputs of the operational amplifier. The diagram shows that in the absence of flow, the heating resistor and the temperature sensor have the same temperature coefficient and their power is equal. If the air flow rate increases, the difference between their power increases due to the cooling of the heating resistor. This change result in a voltage difference across the inputs of the operational amplifier, causing the transistor to turn on. After opening the transistor, the current increase. If the flow rate decreases, then the voltage difference at the inputs of the operational amplifier decreases, which lead to the closing of the transistor. Thus, the circuit compensate for itself.

A reading element, such as a microcontroller, must be connected to the emitter of the transistor. This microcontroller have an analog-to-digital converter to read the change in voltage at the emitter of the transistor.

After analyzing the location of the flow sensor, a printed circuit board was developed for a 40x30 mm sensor. The printed circuit board layout is shown in Fig. 6.

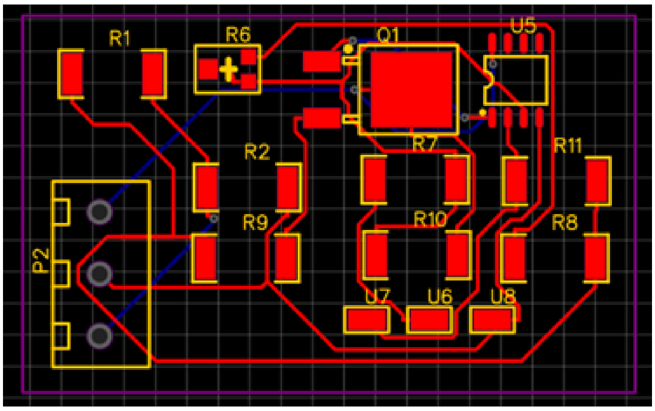

Fig. 6. Air flow sensor printed circuit board.

The 3D model of the printed circuit board is shown in Fig. 7.

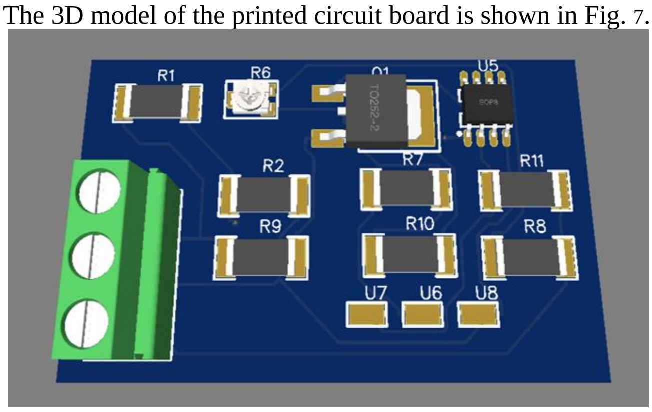

Fig. 7. 3D model of air flow sensor printed circuit board.

The connector on the left side of the board is used to connect the power supply to the board, and to connect the microcontroller output for reading readings from the flow sensor. The contacts of the flow sensor - GND, RT and RH are soldered to the contacts U7, U8, U9.

D. Using computer vision algorithms

An option for improving the system is installing videcams in the premises and a single-board computer Raspberry Pi [12]. A neural network is loaded into the cameras, which analyzes the image, and using computer vision technologies [13, 14] determines the number of people in the room (see Fig. 8). Having received information about the number of people in the room, the controller can independently make a decision on the required air exchange. The decision will be made on the basis of sanitary rule 54.13330 "Residential multi-apartment buildings". Implementation is carried out based on the total area of premises and the number of people. With a total area of the apartment for one person more than 20 m^2, air exchange value = 30 m^2/ hour per person. With the total area of the apartment for one person less than 20 m^2, the air exchange rate = 3 m^2/ hour per 1 m^2 of living space.

Fig. *8*. Recognition of the number of people by neural network.

E. System extensibility

The system is versatile and scalable, because the number of options for combinations of different devices can vary depending on the wishes of the consumer. Additionally, an air conditioner, a radiator, an ozonizer, an ionizer, a humidifier and many other devices and sensors that directly affect the state of the indoor microclimate can be installed. Each additional device is integrated into the basic system, which makes it possible to create an infinitely large number of different variations in the construction of the ventilation system.

IV. EXPERIMENTAL RESULTS

The debugging stand was created to test and debug the system's performance. The stand is divided into 2 rooms with supply valves and a fan built into the walls. The 3D model of the stand is shown in Fig. 9.

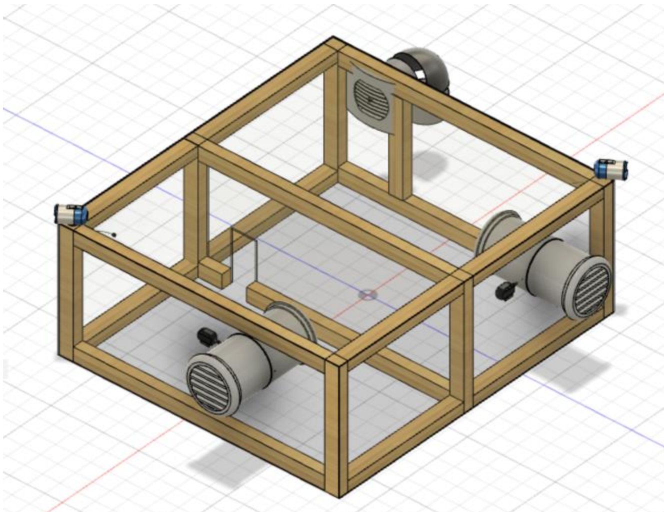

Fig. *9*. 3D model of debugging stand.

The system parameters were tested at the stand:

- fault tolerance of the fan.
- fail-safe supply valve with built-in stepper motor.
- fault tolerance of the controller system.
- fault tolerance of the power supply system.
- the operability of the automatic ventilation power control system based on the number of people in the room.

V. CONCLUSION

During the study, the following goals were achieved:

- A system of monitoring and controlling the microclimate parameters in a room has been designed.
- The possibility of modifying the base system and adding additional devices to it has been explored.
- The application of computer vision within the framework of the integration of the microclimate control system into the “Smart House” system has been investigated.

The climate control system can be integrated into the smart home system. It works well with both other climate control devices and home automation devices. Scalability and extensibility are main advantages. This research can be applied in completely different conditions - from small one-room apartments to industrial enterprises with several hundred workers.

Applying of computer vision has prospects in the development of the Internet of Things. It is possible to monitor air exchange in the room, track the number of workers in the workplace by video surveillance cameras with a trained neural network. It is possible to track cold and blown areas of the room by installing a thermal imager.

Devices from other industries of the smart home can also be added to the system. This system implies the presence of sensors and actuators in all rooms.

In the future, the system can be the core of a smart home system, into which other devices of the Internet of Things will be integrated.

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