Intelligent Distributed System for Indoor Heat Flow Control

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Abstract: In this paper, we consider the software and hardware implementation of an intelligent distributed system for forecasting and controlling the optimal distribution of heat in the room. Prediction is based on a pre-trained neural network model. The system uses calculation results of the one-dimensional heat conduction problem to correct neural model being trained and decides to turn on / off a specific air conditioner depending on the predicted data.

1 INTRODUCTION

The principle of operation of modern air conditioners (Dubolazova, 2009) is based on maintaining the temperature of the room at a given level. The air conditioner generates a stream of air pre-cooling or pre-heating it. When the temperature reaches the desired value, the air conditioner turns off. Air conditioner sensors continue to record air thermal values. When the temperature changes to value above or below the threshold level, the air conditioner switches on again. Thus, the temperature of the room is maintained.

Inverter air conditioners have a special approach to controlling room temperature. Principle of operation of the inverter air conditioner is that it is possible to smoothly (multi-stage) adjust the speed of rotation of the compressor motor, depending on the heat load in the room. For faster achievement of set temperature, the inverter controller increases the speed of rotation of the compressor engine. The air conditioner starts to work in the forced mode until the room temperature reaches the set value. Then the engine speed decreases, but the compressor continues to operate, maintaining a constant temperature with minimal deviations (Nagata, 2015).

This approach has a significant drawback. The temperature sensor located on the air conditioner itself does not reflect the overall thermal picture of the room, because of the characteristics of the premises (external heat sources, batteries, an open window/door, etc.), the temperature in different areas may vary very strongly (Svirina, 2016). Therefore, there is a need to control the air conditioners in such a way that the system of heat distribution in the room reacts to sudden temperature changes in certain areas. Also in the air conditioner does not take into account the work of other air conditioners. The operation of each air conditioner is autonomous and controlled only by reading temperature sensor.

In previously published papers, algorithms for controlling the temperature in rooms and air conditioners were analyzed depending on various criteria. In the article of Tverskoy (Tverskoy, 2012), the principle of controlling the thermal regime of a building with radiator and air heating devices in the heating system is considered. Spitsyn's work (Spitsyn, 2012) is devoted to the analysis of indoor temperature control algorithms. Also, in Nasution's paper (Nasution, 2016) the approach for regulation of air conditioners through controllers with fuzzy logic to achieve energy saving is considered. The researchers of the Swiss Federal Institute of Technology Lausanne present in their works the simulation of the heat distribution in the construction of thermo syphon for high heat flux components (Seuret, 2018).

In this paper, by analyzing surveys in the field of decision-making systems (Phillips-Wren, 2008; Rábová, 2005; Averkin, 2011; Vasilescu, 2011), we propose the implementation of an intelligent system for effective thermal control. The system uses a neural network (Kozadaev, 2006; Santhosh Baboo, 2010; Smith, 2006; Smith, 2007) to predict the distribution of heat based on the history of temperature changes in the room, received from the sensors, which is complemented by data from a numerical calculation of the problem of heat distribution. Based on forecasts, the optimal operation mode of air conditioners is chosen to

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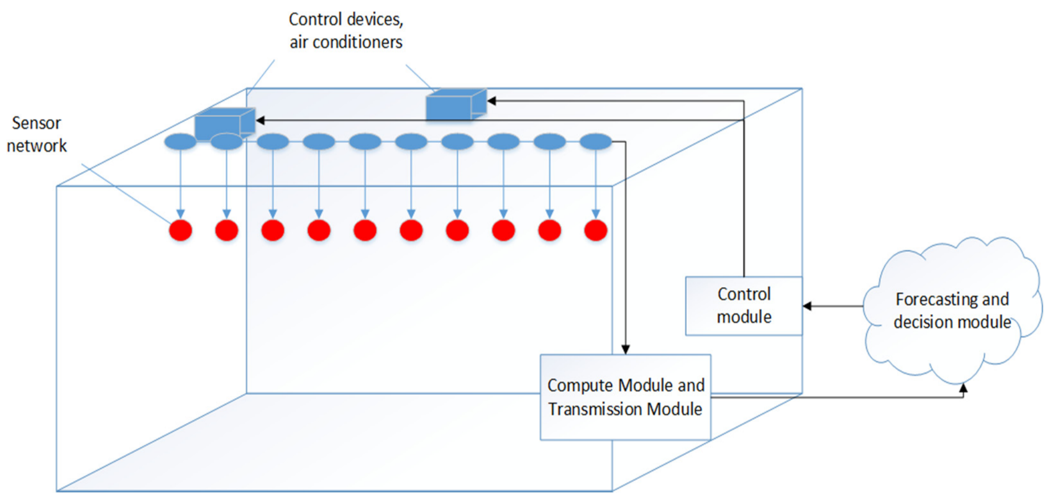

Figure 1: Description of the general system.

achieve the target heat distribution. To predict the thermal distribution, a neural network has been developed, which has been trained by the method of back propagation (Alejo, 2008; Buscema, 1998; Makin, 2006). The calculation of the numerical solution for the heat conduction problem is performed by a computational accelerator based on FPGA (Field-Programmable Gate Array), thus reducing the overall load on the system.

2 GENERAL SYSTEM DESCRIPTION

The system is a software and hardware complex for optimal adjustment of the temperature regime of the room. It consists of a module for collecting, processing and monitoring data on room temperature, a prediction module based on a neural network and a decision-making module.

The data-collecting module transmits temperature data from sensors located along the premises to the computing module and to the prediction module. The computational module performs heat distribution calculations and transmits the calculated values to the prediction module. The prediction module, based on a previously trained neural model, provides predictions of temperature distribution for various operating conditions of air conditioners. The decision-making module selects the optimal operation mode of air conditioners to obtain the target function of heat distribution in the room and transmits the corresponding signals to the devices controlling temperature condition.

3 DATA COLLECTING MODULE

The primary collection and transmission of temperature data from sensors is performed by a hardware module based on Arduino UNO. The network of temperature sensors will cover the perimeter of the considered area (room). The module converts the values into the form of floating point numbers (IEEE 754, 32 bits). Next, the values are transmitted to the computing device (FPGA) via the I2C data transfer protocol.

4 COMPUTING MODULE

A hardware prototype of a calculation module based on the FPGA model Nexys 4 with Artix-7 family XC7A100T-1CSG324C chip was implemented. The module uses a microcontroller with Wi-Fi interface ESP8266 for informational interaction with the prediction module. The computing module calculates the problem of heat conduction in the room.

To calculate the heat distribution, heat conduction equation is used, which looks as follows:

$$U_t = a^2 U_{xx}, \text{ where } x \in [0, l];\ t \in [0, T], \quad (1)$$

with initial and boundary conditions:

$$U(x, 0) = U_0,$$
$$U(0, t) = U_1,\ U(l, t) = U_l.$$

The finite differential scheme form of equation (1) has the form (Samarskii, 2001):

$$U_i^{n+1} = U_i^n + \frac{a^2\tau}{h^2}(U_{i+1}^n - 2U_i^n + U_{i-1}^n) \quad (2)$$

where τ - grid step along the time coordinate, h - grid step along the spatial coordinate, a^2 - coefficient of thermal conductivity.

Problem (2) is solved by the finite-difference method using the Jacobi iteration method (Kuznetsov, 2007), in which the values of points with indices

$i-1, i, i+1$ from the previous time layer are used to calculate the value at each point *i*.

The computing block for each iteration consists of three sub-blocks. The computational device operates with real numbers using the Floating-Point Operator IP Core (Floating-Point Operator v7.1, 2017). Calculations are made at a frequency of 100 MHz.

Figure 2 shows the logic diagram of the computational module that computes the values of each iteration, where *result_1* is the result of the first calculation sub block, *result_2* is the result of the second calculation sub block, *result_3* is the result of the third calculation block.

For the sequential transfer of intermediate data between computational operations, finite automata with two states are developed for each of the sub-blocks:

- *STATE_0* - waiting status of incoming parameters. On receiving input values, the machine performs the calculation.
- *STATE_1* - result output, input parameters reset and switching machine to the pending state.

The results of the computational block are recorded in the generated transfer queue. The core of the standard IP directory FIFO Generator (FIFO Generator v13.1, 2017) implements the data transfer unit.

The data transfer unit in turn transmits data to the Wi-Fi module via the i2c protocol. The data transfer rate was reduced to 250 bytes/s due to limitations because of the characteristics of the transmitting device. Wi-Fi module is programmed using the Arduino IDE. Wireless network is used to transmit data to the prediction module.

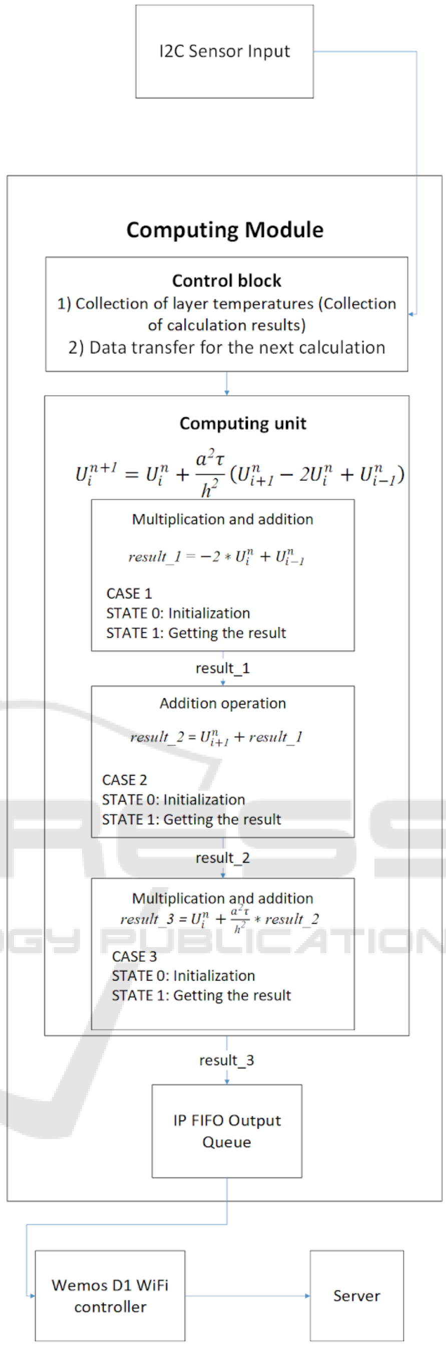

Figure 2: Diagram of the computing unit.

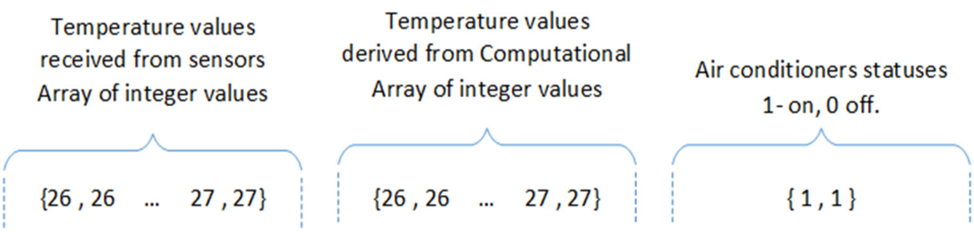

Figure 3: Input data structure.

5 INTELLIGENT DECISION MAKING SYSTEM

The intellectual component of the system consists of two modules: a prediction module and a decision-making module.

Prediction module. The heat distribution prediction module is designed as a neural network model trained using error back propagation method. The following parameters are selected as model input parameters:

- history of changes in the temperature array obtained from the sensors;
- computed data (based on historical values) using the heat conduction model;
- status of air conditioners, where 1 - air conditioner is turned on, 0 air conditioner is turned off (00 - both off, 01 - first off, second on, 10 - first on, second off, 11 - both on).

Figure 3 shows the general structure of the input data.

The output structure corresponds to an array of temperature values of the expected data.

The artificial neural network has four layers, an input layer with 12 neurons, 2 intermediate layers of 7 neurons, and an output layer with 10 neurons. The neural network was trained at 7500 and tested on 1500 data sets. The parameters of speed and moment of learning are 0.01 and 0.1, respectively. This network structure is chosen empirically and provides accuracy with an error of no more than 5%.

The expected data are presented in the form of 317 unique sets of values from sensors obtained from experiments. The forecasting model assigns a set of input values to one of such sets, so when building a forecast, the neural network solves the classification problem.

Decision making module. The system makes decisions based on heat distribution predictions for various combinations of air conditioner operation modes. The required temperature condition is represented as a linear target function with a predetermined temperature. The forecast of heat distribution for each of the modes of operation are compared with the target function. The system selects the mode with the smallest average deviation from the target function (Figure 4). The parameters of the selected mode are transmitted to the air conditioners as a control signal. Air conditioners according to the command maintain the desired temperature condition. The whole process is performed in a cyclic manner with a period of 2 minutes.

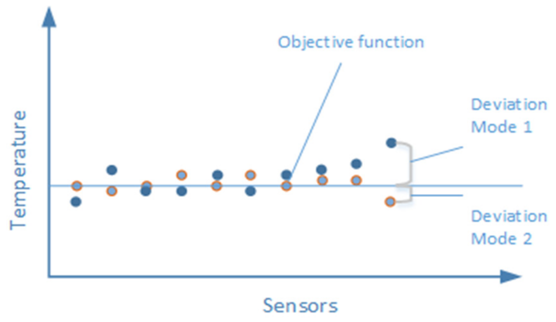

Figure 4: Temperature distribution graph for two modes.

6 CONCLUSIONS

The paper considers an approach to the software and hardware implementation of an intelligent room air conditioning system. The system has data collection sensors that transmit in real time information about the current heat distribution in the room. The data is saved for later use for learning the neural model. The neural model is able to predict the further distribution of heat depending on various parameters and choose the optimal operation mode of air conditioners. Implemented a computational accelerator based on FPGA, the results of which are also used to make predictions.

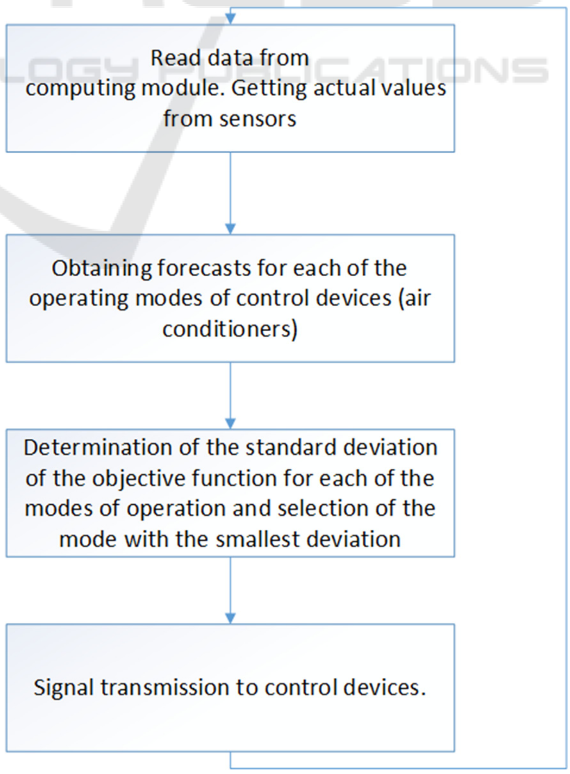

Figure 5: The cycle of the system.

It is worth to mention that the system, before reaching the target function, may have time to perform several control cycles in different regimes. That in turn will provide a smoother change in temperature of the room.

Thus, we constructed a prototype of a self-sufficient intellectual distributed system, which, depending on a given objective function, can systematically regulate the temperature mode of a room.

In the future, it is possible to improve the system by adding operating modes with different powers for air conditioners and adapting the system for non-linear objective functions.

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