

DIAGNOSTIC SYSTEM FOR THERMAL MONITORING OF BUILDINGS

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Abstract – The paper presents properties of a system for measurements of quantities which determine thermal state of buildings. The system can be used both in investigations of thermal processes in buildings and for monitoring thermal processes to perform an energy consumption audit. Each measuring instrument is supplied by a separated task, which enables simple modification of programs and introduction of new instrument tasks. The diagnostic system is managed from a local computer by using the program written in the LabView environment.

Keywords: thermal diagnostic of buildings, measurement system, wireless communication.

1. INTRODUCTION

Purpose of building thermal diagnostics can be defined as the determination of heat flux supplied to and discharged from the building, resulting in the final energy balance of the object. These activities are carried out for obtaining two kinds of effects. Firstly, knowing the important factors causing heat loss in a building can be used to reduce them, which is the main task of an energy audit of existing buildings, and to minimize these losses is an important aspect of the design the new buildings. Second, the online monitoring of building thermal state allows to project automation systems that optimize the thermal balance and allow the same to save energy [1]. Discussed here diagnostic system has been built for the purposes of carrying out the measurements characterizing the thermal state of the buildings online, which means that the measurements are performed in-situ. Thus, the assumption that it is a portable system that can be installed in various types of buildings and set of buildings. The system is also intended for use in research experiments.

In order to set the properties of the system allowed the integration of different types of measuring equipment, currently used for measurement the thermal state of the building. This apparatus is constantly upgraded by the manufacturers and thus changes its metrology properties and used communication interfaces. To allow the use of such devices provided adequate flexibility of the system, defined as the ability to integrate various measuring apparatus, which is used currently and in the near future for the measurement of the thermal state of the buildings. In addition analog module was built, suitable for use in the

system of different types of sensors with voltage output, current or resistance.

The integrated system uses the ability to communicate with system operator by Internet and wireless communication to ensure flexibility in the creation of a variety of configuration adapted to the implementation of the measurements. Described system has been built from the ground up using the latest hardware and software solutions. This system integrates the typical measuring instruments used to heat buildings diagnostics and let for attaching sensors for specific research experiments. Local transmission within the building takes place in a wireless manner, and remote communication is done via standard web-based solutions and mobile networks.

2. DESIGN OF MEASUREMENT SYSTEM

General structure of the system is shown in Fig. 1. Measurements in the system are made using specialized instruments, organized in measurement nodes, labeled N1, ..., Nn. Each of the nodes is managed by the controller node supervising the flow of information through a serial interface. The function of a multifunctional device driver fulfills the device called communicator and marked in Fig. 1 by the symbol C.

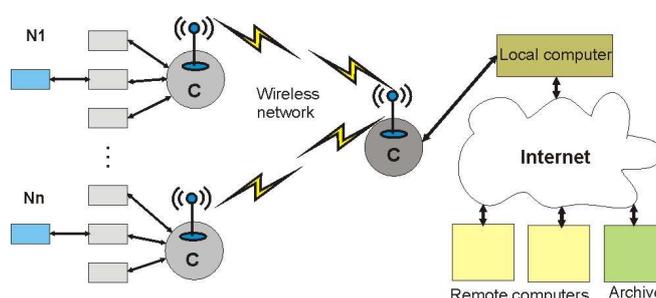


Fig 1. General structure of the system of thermal building diagnostics, N1,...,Nn – measurement nodes, C- communicators.

Generally the system communicator can meet the four functions:

- measurement node controller, managing sets of measuring instruments via wired serial interfaces RS-485 and RS-232,
- wireless network coordinator, managing communication in a ZigBee network,

- device coupling wireless network with the local computer, which is used to manage the system from the building,
- wireless router witch is the radio signal amplifier.

The main component of the system is the measurement node, organizing the work of the measuring instruments as shown in Fig. 2.

The main element of node is a communicator acting as a controller S. The basic tasks of controller can be defined as:

- communication with measuring instruments,
- archiving measured data from all the instruments,
- communication with the coordinator of the wireless network.

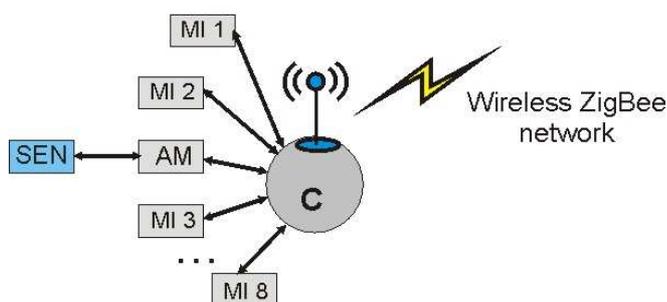


Fig 2. Structure of a system measurement node; C - node controller, MI – measurement instrument, AM – analog module, SEN – sensor

To one controller can be connected up to 8 devices, including up to 4 analog modules. The system currently integrates such a instruments:

- exhaust gas analyzer ,
- electricity energy meter,
- multi-channel temperature logger,
- weather station,
- differential micromanometer,
- ultrasonic flowmeter.

The task of the analog module is to measure the analog quantities from different sensors like: resistance, voltage or current. The main component of this module is ADuC836 microcontroller from Analog Devices [3]. It includes two measurement channels with 16-bit AC Sigma-Delta converters, one of the circuits comprises an amplifier with adjustable amplification factor digitally. The microcontroller is equipped with a temperature sensor, which gives the opportunity to correct errors of temperature measurement channel. The module also includes a reference voltage source with high temperature stability, which enables the measurement with sufficient accuracy. The maximum sampling rate is about 100 times per second, which fully meets the needs of sampling the instantaneous values of signals characterizing thermal processes.

The measured data are collected on a regular basis by the controller node and also transmitted via the wireless communicator working as a coordinator of a wireless network connected to the local computer using the USB connection. The main task of the local computer system management is:

- configuration of the system, involving the transfer of information to the nodes with which devices should to cooperate and to determine measurement parameters (type of the measured quantity, sample rate, etc.),
- current measurement data receiving and archiving,

- visualization of measured data,
- communication with the operator.

Local computer is connected to remote computers via the Internet. One of the computers acts as a remote database for storage and share of all measurement data which were obtained using the system. Other computers are used as remote consoles, allowing for the realization of all the tasks from distance. The system generally shown in Fig. 1 can operate in one of three forms, with characteristic structures. These are:

- centered structure,
- decomposed structure ,
- distributed structure.

Centered structure of the system is designed to carry out measurements only in one room, while it is possible to direct wireless communication between the driver and the coordinator node by wireless network. In decomposed structure system is used when measurements are made simultaneously in several remote areas like different rooms and floors of building.

A system with distributed structure is used when the measurements are carried out in remote areas or in separate buildings. In this situation, it is not possible to direct radio connection between the nodes and the coordinator and routers must be used witch do the appropriate radio signal amplification.

On the radio track between the node and the coordinator can work a few routers, which allows for getting in such a system fairly large distance between the nodes and the coordinator. In addition to the described three basic structures, in practice, can also be used a combination of them. This capability is mainly determined by the properties of the Zig-Bee standard applied to the wireless transmission system. It should also be noted that the individual nodes of the system can operate autonomously under the supervision of a controller witch meets the registration functions.

3. HARDWARE AND SOFTWARE DESIGN OF COMMUNICATOR

Communicator is equipped with a microcontroller ATXMEGA128-A3, containing 120 MB flash program memory an additional memory area of 8 KB, which may be used for data and 8 KB of memory containing the bootloader. The internal data memory has 8 KB EEPROM non-volatile memory and 2 Kbytes of SRAM static memory. To measure astronomical time used MAXIM DS1307 chip [5]. The microcontroller supports 5 transmission channels in RS-488 standard, 3 channels of RS-232C standard equipped in optoisolation, and one USB port, used for communication with the local computer.

Communicator's microcontroller works with a external memory Atmel DataFlash 64 MB [6], which creates a local database for storing measurement results. One result is a 16-byte record which is a data structure consisting of a 32-bit identifier, 32-bit timestamp, a 32-bit result of the measurement in floating point format, 8-bit channel number and mark of the end of the record. Thanks to this memory a result of measurement can be saved even after prolonged absence of wireless transmission.

Wireless communication between the communicators uses ATZB-A24-UFL Atmel chip working in a ZigBee standard [7], which is connected to the main microcontroller

using the RS-232C interface. This module at transmitter full power is capable of transmitting information over a distance of 1 km in the absence of obstacles. It can be configured as a wireless terminal device [11]. If the module performs the function of a router, the communicator is used to amplify radio signals, and then the main microcontroller enters the sleep state.

Communicator can be powered from three sources: the power network, internal batteries, rechargeable via external charger or external battery. Different types of power supply are switched automatically using the controller. Thanks to the possibility to sleep of the main microcontroller between moments of its use by measuring instruments, it can work very long without power supply. When communicator serves as coordinator of the wireless network, it is powered from computer via the USB port.

Depending on their function communicator's software can operate in the node controller mode or a wireless network coordinator mode. In the first case acts as a ZigBee end device of the network. Then the program of main microcontroller performs the following actions:

- checks the current configuration of measuring instruments in the node, and on this basis, starts each measurement task and executes cyclic activation of measuring instruments,
- activates subroutines (measurement tasks) supporting the measuring instruments connected to serial ports,
- carry out the radio transmission of measurement results to a central database, which is organized on a local computer,
- perform archiving measurement results in a local database, located in the non-volatile memory of the communicator.

The controller node has to perform multiple tasks concurrently. To enable this type of operating system developed RTOS (ang. Reduce Task Operating System), realizing the task switching [8], and acting on the principle of the division of time [9]. This system enables the realization of 8 tasks concurrently and independently from them handling the system interrupts signals. Communicator is introduced into coordinator mode when it is connected to the local computer (laptop) which is supervising the operation of the entire system, including a program of coupling a central database with local databases. This program performs two tasks:

- reads from a central database system configuration and sends the port settings for the appropriate controllers nodes,
- receives from controllers nodes the measurement results stored in the local databases, and sends them to a central management software database for archiving.

In coordinator mode communicator service does not perform interrupt signals of the serial ports and only supports interrupt signals from USB and ZigBee module. The controller in this mode is used to copy bytes coming from USB to ZigBee device or vice versa.

4. LOCAL COMPUTER SOFTWARE

The main task of this software is to manage the measurement process in the system. It involves setting up a system for the implementation of the measurement, supervising their execution with visualization of measurement data, acquisition of data and locating them in a central database. These actions are the result of the implementation of two independent applications: visualization and management software system, called in

short program management, and communications program used to exchange data between the local computer and the coordinator of the wireless network [10].

The idea of exchanging data between applications results from the construction of a central database, the structure shown in figure 3. This database contains the measurement results and system configuration data. Management software allows the operator to enter data and to indicate measurement data for visualization. Next the communication program updates the database, saving data results from the measurements, and also transmits the configuration data to the local database controller nodes.

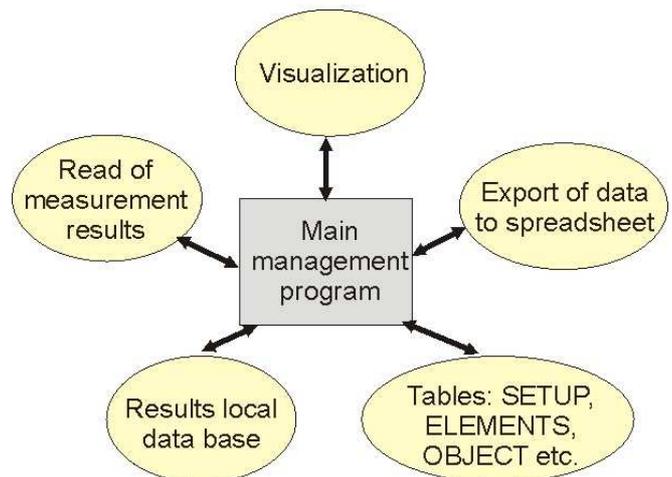


Fig 3. Scheme of information interchange between the tasks realized by management software on local computer

The database consists of five tables:

- RESULTS - includes measurement data,
- SETUP - contains the current configuration of the system (node addresses, connected devices, measurement parameters),
- ELEMENTS - this is a list of devices that can be used in the system, includes types of measured quantities, units, descriptions and status information,
- METERS - used to store descriptions of measurement devices used in the current system (the place of installation, the type of the instrument from ELEMENTS table),
- OBJECTS - a list of building and rooms intended for heat audit.

System management program, works in LabView environment and allows for the implementation of three basic tasks:

- initial configuration of the system before starting the measurements,
- preview the measurement results, both current and historical,
- export of measurement data during measurement and after their completion.

The activities performed during these tasks are selected using bookmarks from management program [4].

System configuration is necessary when making the measurements in the new building. To carry it out the new object first must be defined by entering its description to OBJECTS table, and then should be specified the devices supported by the system by filling the ELEMENTS table. Another work is the selection of a set of devices currently

used in the new system together with its description, the place of install the devices. The last step of system configuration involves assigning devices to specific nodes, selecting the measured values and the definition and measurement of transmission parameters (table SETUP).

The purpose of visualization is to display the measurement results in graphical or tabular form, and in addition it is possible to check the status of instruments used in the system. Results can be viewed in real time, eg. From the last 10 minutes, or browse the archive results by specifying the beginning and end of the desired interval.

Each form of visualization can be adapted to the requirements of the system user. It can be defined multiple screens with graphs, and for each screen is ability to specify the number of display sizes, the size of the graph, etc., Are also possible: changing the scale, chart type and read the measurement data using the cursor keys and copy the graph to the clipboard. Simultaneous opening of multiple windows of information on the different measured values and change their size allows to customize the appearance of the screen in real time to the user's needs.

Measuring system management program allows to upload the selected measurement data into an Excel spreadsheet. Output results are the arithmetic means in a given period of time. Before creating the report it is a possibility to indicate measured quantities, the beginning and end of the data and the time period for which the average is calculated.

6. CONCLUSIONS

Built system is characterized by high structural flexibility, which allows relatively easy to adapt the system to carry out thermal measurements in different types of objects, including apartment buildings and sets of couple

buildings. Measurements are carried out continuously for many days, and the ability to oversee them remotely via the Internet frees the operator from the presence on the object of research.

Where communicators are used as loggers they can store measurement results from the period of about 10 days. In this system version it is possible to use more than 100 instruments and analog modules.

System is indented to use in thermal diagnostics of buildings and allows to perform an accurate thermal audit.

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