

Hardware-software and algorithmic provision of multipoint systems for long-term monitoring of dynamic processes

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Abstract an example of information-measuring systems for climate monitoring and operational control of energy resources consumption of the university campus that is functioning in the Altai State Technical University since 2009. The advantages of using such systems for studying various physical processes are discussed. General principles of construction of similar systems, their software, hardware and algorithmic support are considered. It is shown that their fundamental difference from traditional SCADA - systems is the use of databases for storing the results of the observation with a specialized data structure, and by preprocessing of the input signal for its compression. Another difference is the absence of clear criteria for detecting the anomalies in the time series of the observed process. The examples of algorithms that solve this problem are given.

1. Introduction

In studies of some physical processes, there is a need to collect data simultaneously from multiple sites located on the monitored object or taken from different areas of the observed phenomenon. This kind of research is particularly characterized in the study of thermal fields and various processes related to heat and mass transfer and meteorological observations [1-4]. Obviously, depending on the problem being solved and the nature of the monitored object, process or phenomenon may require entirely different equipment, measurement technique and processing the received data with its application, and various methods for its storage. For example, to study the temperature processes on local objects, the use of pyrometers, provides a complete picture, such as [5]. However, they are not able to monitor the processes that occur over large areas, for instance, when it is necessary to observe the temperature distribution in the rooms of residential buildings or other man-made structures.

For such purposes, measurement devices based on Resistance thermometers or thermistors are better suited, which are presented in abundance in the market of industrial and scientific equipment, such as [6,7]. However, such devices cannot by themselves solve the problem of collecting, storing and processing data and, again, are not oriented to collect similar data from a large number of channels. For these purposes often use data loggers [8,9], but they have a very limited number of channels. In addition, they are quite expensive, focused on the use of deferred viewing of recorded information and unsuitable for solving the operational monitoring with fully automatic collection and processing of current data. Therefore, more suitable solutions for the class of tasks considered in this paper are monitoring systems [10,11]. However, they also by themselves cannot solve the problems of research, as they focus is only on the transfer of data through communication channels.



Therefore, to solve a number of specific problems relating to the implementation of long-term multi-point temperature monitoring, as well as the monitoring of other parameters of the processes that occur over large areas and which are continuously changing over time, requires the use of specific software, hardware and algorithmic solutions. Consider one of the possible variants of solutions implemented in climate monitoring and operational control of energy consumption, Altai State Technical University campus system and dedicated to this work.

This work is also devoted to consideration of one of the possible solutions implemented in the system of climatic monitoring and operational control of energy resources consumption in the campus of the Altai state technical university.

2. Used equipment and architecture of the facilities

The experimental version of the mentioned system has begun to function since 2009. Its description was the subject of a series of publications, for example [12, 13], so the focus here only on the most basic aspects.

2.1. Structure of monitoring system

A generalized block diagram of the system similar to the block diagram of typical SCADA – system [14-16] is shown in Figure 1 and includes a remote terminal unit (RTU), master terminal units (MTU) and a server application with a database.

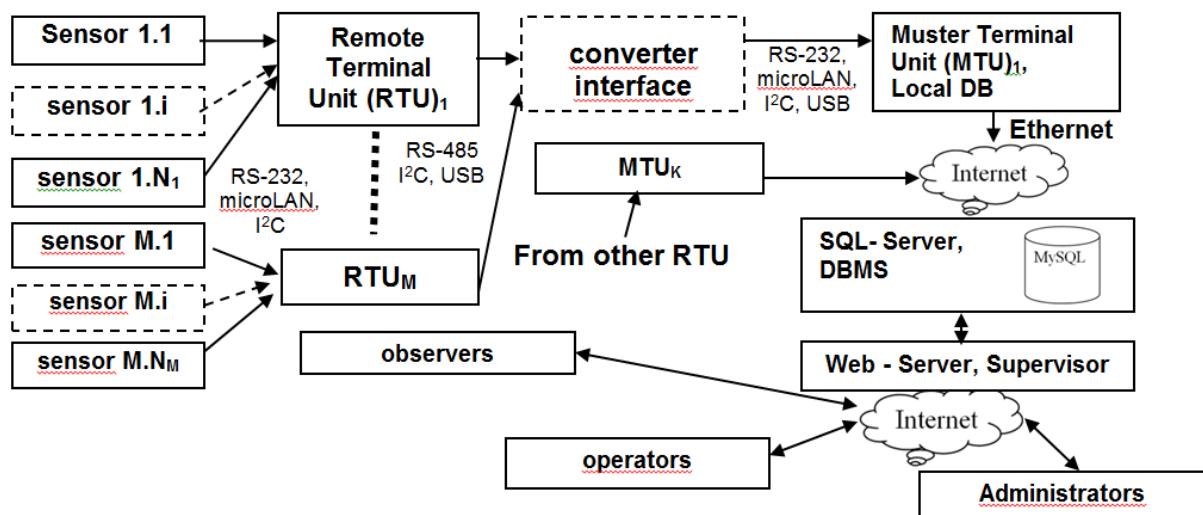


Figure 1. The generalized block diagram of the monitoring system.

The feature of the system is its heterogeneity, due to the variety of sensors connected to it and the specific topology of the distributed network. Converter interface is used only when the connection between the RTU and MTU was maintained through the interface RS485. As RTU was used programmable logic controllers (PLC) i7188D, as well as OEM-modules Arduino-Nano and Arduino-Uno. In the early stages of system design, MTU was developed on the basis of AtMega8 and AtMega64 microcontrollers. The function of MTU can be performed either by a technological computer, or by an Arduino-Mega module with an Ethernet Shield expansion card, or by a Raspberry Pi microcomputer. It is also possible to directly connect sensors to the MTU if the number of sensors in its location is small.

2.2. Sensors

Theoretically, it is possible to connect the widest range of primary measuring transducers to the RTU with minimal hardware costs. In this development, taking into account the range of problems solved by the system, they were used as:

- temperature sensor DS18S20 Dallas Semiconductor firm (-55 ... 125°C, measurement accuracy 0.5°C, sensitivity of 0.0625°C)
- temperature and humidity sensor DHT22 (humidity 0 ... 100%, accuracy of $\pm 2.5\%$, sensitivity 0.1%, the temperature -40°C ... + 125°C, accuracy $\pm 0.5^\circ\text{C}$, sensitivity of 0.1°C)
- a light sensor on the basis of LEDs (0-100 000 lux, accuracy 1%, sensitivity - 0.1%)
- Ultrasonic 3D-Anemometer of own development based on ultrasonic sensors T/R40-18U [17]
- pressure sensor BMP085 (300-1100 hPa, accuracy ± 4 hPa)

In addition to these, the system also uses sensors for monitoring power supply systems, and life support on the university campus, such as heat meters and flow meters for hot and cold water.

3. Used software

During the system development, preference was given to the free software. Almost all software was created in C language. At the lowest level of the hierarchy of monitoring system, RTU and MTU were implemented using microcontrollers from Atmel, as a development environment was used either AVR studio or the Arduino IDE. In MTU based desktop computer for data transfer with RTU on the SQL server was used multi-threaded application written in Java based on framework J-SCADA [12]. As an operating system, its own Arduino operating system was used, and at the MTU level different versions of Linux and Windows. In RTU on the basis of industrial i7188 controllers, the Mini-OS operating system was used. The basis of the server software was made by the Apache web server, MySQL DBMS, and also the JavaScript, PHP and HTML languages.

4. Structure of database

One of the important tasks of the developed system is the task of long-term storage of massive amounts of collected data. Such data itself, such as any weather information may be of interest and are necessary for improving algorithms for their processing and retrospective scientific research. In this regard, considerable attention is paid to how compactification of stored data, and provide quick access to them. In part, this was achieved through the use of appropriate compression algorithms and partly - by applying the appropriate database structure [18]. It is based on three principles, which include data partitioning into separate groups that are close to the sampling interval, the data normalization in order to store them in an integer compact form, and the transition from timestamp in the format "date + time" to storing the number of time intervals from the beginning of parameter registration.

5. Used algorithms for data processing

As a part of the development of signal processing methods of research was carried out in two directions. The development of signal compression algorithm optimized for the type of recorded data, and the development of algorithms for violation identification of the processes flow.

5.1. Algorithms for compressing data

In the studies, along with normalization to integer format and transfer to records of time in the sampling intervals were considered two approaches for data compression, lossless compression and lossy compression. Lossless compression is based on the modified difference schemes of data transmission and RLE – methods [19-22]. For lossy, two options were considered. The first was based on the approximation of segments of the recorded sequence of samples by polynomial or trigonometric functions with the number of terms of the series in the range of 5-9 [23]. The second was a modification of the method RLE supplemented using nonlinear filtering algorithm. Its essence is that the transition level to the new value signal is generated only when the input signal is steadily (i.e., over several cycles) changes its value by more than a certain safety range (uncertainty interval), whose

value is determined by the level and nature of noise component. The comparison of these compression techniques showed that for temperature monitoring, both inside and outside the room most effective was the last method that has allowed, depending on the nature of the temperature change with the time and the presence or absence of abnormal processes, to provide data compression 60 ... 80 times [24].

5.2. Algorithms for anomalies detection

One of the most important tasks of the developed system was the detection process for the continuous observation of temporal changes in the parameters of the monitored processes (power and consumption, temperature, pressure and humidity in auditoriums and outdoor) violations of the regularity of their occurrence. The nature of such violations may be very different. For industrial processes, they are often accompanied by a variety of violations of technological processes, that is, the so-called emergency situations. For natural phenomena, the presence of various anomalies is a more common phenomenon, which is observed when a particular combination of many different factors and therefore represents a particular interest for the researcher. From all variety of manifestation of such anomalies, this study considered only three of the most common forms. These include the appearance of sharp drops, outliers in the observed signal and cyclic violation of the periodic processes [25]. For these types of anomalies have been proposed modifications of known statistical methods for detection of statistical deviations [26-29]. The essence of the proposed methods for identifying outliers and level differences was that the recorded signals were allocated in fixed length time intervals, where were their statistical properties, which were compared with each other in adjacent intervals. In this case, the length of the intervals was chosen to be comparable with the length of the outliers or the edges of the level differences. For cyclic processes, the violation of cycles was detected by exceeding the threshold of the signal, equal to the difference between the samples of the current period and the accumulated and averaged samples of the previous cycles. In contrast to the known similar solutions, in the proposed modification, in order to reduce identification errors, accumulation of averaged samples took into account the signal trend. This solution is especially effective in observing street temperatures since it has the most significant trend in diurnal fluctuations.

6. Possible scopes and achievable task

The developed system was primarily designed for continuous automatic monitoring of campus life-support systems. However, the developed algorithms for anomalies detection, especially in cyclic processes can be successfully used for the analysis of processes in the environment. In particular, Figure 2 shows the cycles violations of the temperature dependencies caused by heavy rains in the city of Barnaul.

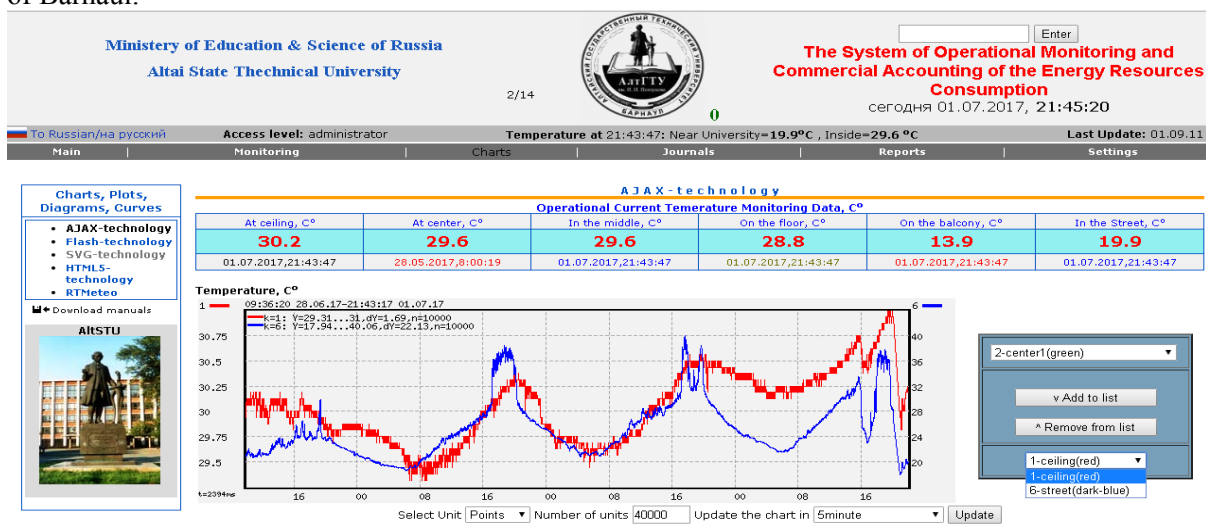


Figure 2. Observation of cyclic violation and fluctuations of the ambient air temperature.

The high temporal resolution of the temperature sensors (0.7s) and their small time constant (about 5 seconds) allow to successfully use them for research of turbulent phenomena and local inhomogeneities in the atmosphere. As seen from the same figure, in the temperature graphs have smooth portions and portions with a high frequency of temperature fluctuations caused by local inhomogeneities in the air environment.

If the observed fluctuations supplement observation of solar irradiance fluctuations caused by inhomogeneity of the cloud cover, it is possible in this way to record the amount of energy absorbed by the underlying surface. A particularly promising in this respect to combining these studies with the methods of recording the absorbed energy of the satellite monitoring data [30, 31].

Sensors used in the system also have an excellent resolution and high temperature stability readings [32] which allow to use them for studying the phenomena associated with the redistribution temperature fields in premises caused by any factors. Figure 3, shows the system possibility to detect temperature fluctuations in the room as a result of operating the electric heater, and Figure 4 - to study processes associated with the room ventilation.

During the studies, it was found that a person can raise the temperature of a room with a volume of about 30m^3 by $0.1\text{-}0.5^\circ\text{C}$ and direct sunlight entering into it can raise the temperature by $1\text{-}2^\circ\text{C}$. This high sensitivity allows to solve a number of important special problems related to energy saving. For example, knowing the amount of energy supplied to the premises (most simply to do it when using an electrical heating experiment) and the temperature difference between the room and the street, it is not difficult to find the thermal resistance of the external wall of the room according to the known from thermophysical relations (provided that the same temperature is maintained in the neighboring rooms as in the room under examination). This will allow in the future to develop a "smart" thermal control system that optimally takes into account both the environmental conditions (light, temperature, wind) and the condition of the room (ventilation, people presence, turning on the electrical appliances, etc.)

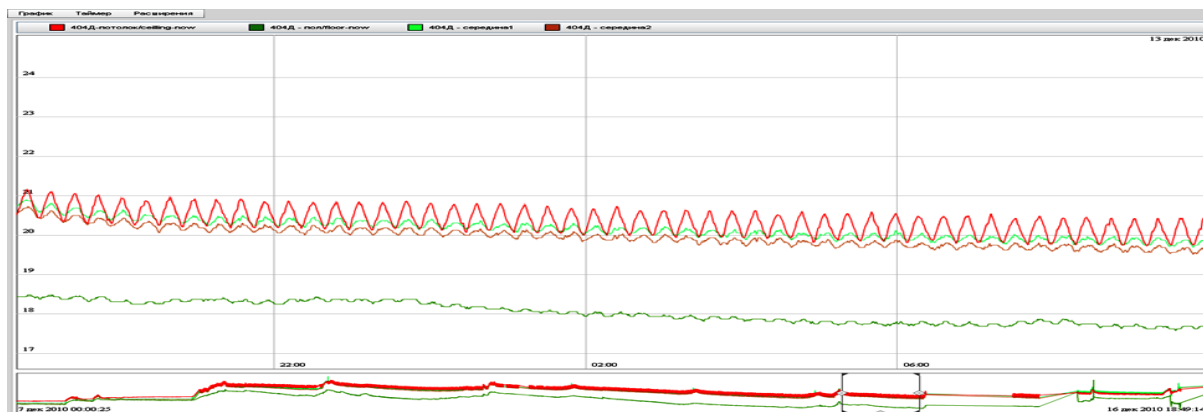


Figure 3. Temperature fluctuations at different points in the room caused by the operation of the electric heater.

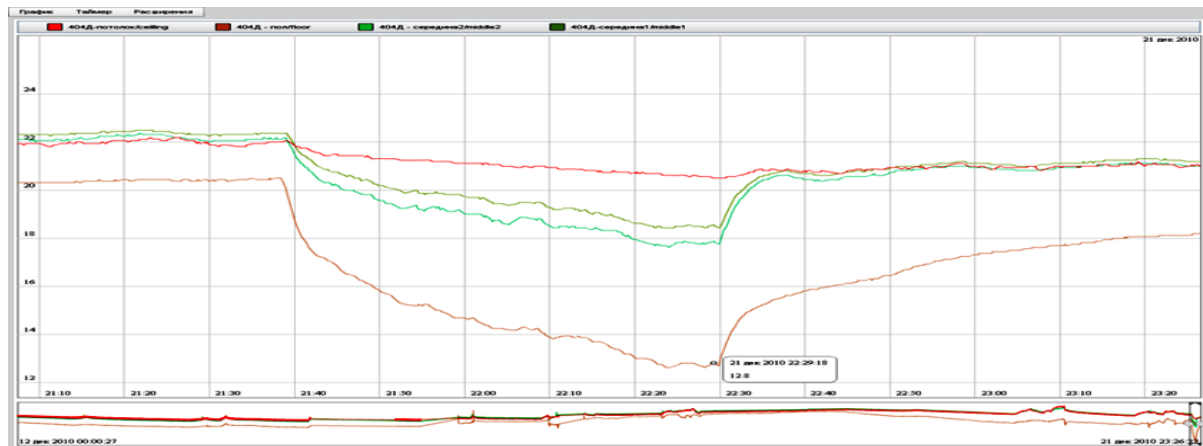


Figure 4. Negative temperature outliers in the room as a result of its ventilation.

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