Automated Training Laboratory Bench for Studies of Thermophysical Properties and Thermal Processes Based on a Programmable Controller SDK-1.1M

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Abstract. This article will focus on the new controller for thermophysical research, intended for use in the educational process. The controller contains nodes of power supply, automatic control of the cells and auxiliary devices for collecting, storing and processing primary information. The controller has a built-in control panel with a functional keyboard; it can display the measurement results on a Smartphone or PC.

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Thermophysical measurements belong to the category of purely indirect measurements. To register temperature fields and heat fluxes, thermocouples and thermistors are used everywhere, which convert the temperature into electrical signals. Therefore, in the composition of any thermophysical measuring device, along with a heat cell, an electrical measuring complex is equally present. A very strict requirement is imposed on its technical characteristics due to low-current electrical signals of thermoelectric sensors.

A controller designed for servicing heat-measuring cells should be a complex multifunctional electronic device operating according to a given program, which includes several dozen interconnected procedures, controlling all stages of a thermophysical experiment.

For many years, the employees of the Department of Thermophysics of the St. Petersburg State Academic Technical University (now the school of biotechnology and cryogenic systems of the ITMO University) and the department of computer engineering ITMO (now the faculty of software engineering and computer systems of the ITMO University) participated in the joint development of a number of thermophysical devices of the ITS series and TFK controllers. The results of this collaboration are detailed in publications. [1-6].

Fig. 1. Picture. 1 Controller TFK-2.2 [6]

Together, a number of devices for thermal measurements of various materials were created (Table 1.)

This article will focus on the new controller for thermophysical research, intended for use in the educational process. The controller contains nodes of power supply, automatic control of the cells and auxiliary devices for collecting, storing and processing primary information. The controller has a built-in control panel with a functional keyboard; it can display the measurement results on a Smartphone or PC. The controller provides simultaneous operation of up to 8 primary measuring sensors with a threshold sensitivity of about 10 V with sampling resolution of sensors from 0.02 s or more. There is the possibility of working with a personal computer. Control and information signals are transferred between the PC and the controller via the USB port.

The laboratory complex allows you to study thermal processes in the temperature range from minus 196 C to 100 C: thermal conductivity and thermal resistance; heat capacity, enthalpy, heat and power of internal sources; initial moisture content and cryoscopic temperature; to conduct studies of the kinetics of phase and structural transformations in moisture-containing materials.

Table 1. Devices for measuring the thermal properties of the ITS family.

ITS–I–1	Measurement of thermal conductivity and thermal resistance of various heat-insulating, building and structural materials near room temperature.
ITS–c–2	Research of thermal and humidity characteristics of finely dispersed moisture-containing materials in the temperature range (–30 ... 20) . The thermal properties of any substances and materials, both liquid and solid, can also be studied.
ITS–lc–3	Measurement of thermal conductivity and heat capacity of substances at atmospheric pressure in the temperature range (–30 ... 80) .
ITS–c–4	The study of thermal and humidity characteristics of materials in the temperature range (–30 ... 20) . It is possible to study the thermal properties of ordinary substances and materials.
ITS—5	Measurement of heat capacity at atmospheric pressure in the temperature range (–30 ... 80) C.
ITS–q–6	Measurement of internal heat sources arising from chemical reactions, in the processes of dissolution, oxidation, etc.
ITS- λc-20	Measurement of thermal conductivity, thermal resistance and heat capacity of solid electrical insulating materials.
ITS-λ-20	Measurement of thermal conductivity, thermal resistance and heat capacity of solid non-metallic materials

At the moment, we can confidently say that instrument controllers designed for close integration with devices for measuring physical quantities are cyber-physical systems (CPS)[7]. If we recall what the devices built 10, 20, or 40 years ago looked like for measuring such quantities (for example, such as the IT-lambda-400 thermal conductivity meter developed in 1979), we can see that most of the attention was concentrated on the physical part of the experimental setup, while the computational part was primitive and consisted of a unit for measuring physical quantities, a primitive heater control system and practically did not carry any intellectual component, in fact, it was a certain electronic voltmeter. At the moment, we have huge computing power available thanks to a cheap elemental base, we have extensive experience in digital signal processing, we are able to use neural networks and the first prototypes of artificial intelligence to process information. Currently, embedded systems (ES) are no longer simply integrated into a physical measuring device, they are its inextricable component, in the same way that the brain is an inextricable component of a human. The tight integration of the ES and the measuring device imposes restrictions on the design methods of such devices. In this article, we demonstrate the capabilities of CPS for organizing the training process for both physicists and specialists in computer engineering (CE), if physicists are primarily interested in measuring physical quantity as such, then students associated with CE will be interested in methods of reducing the measurement error, filtering signals, methods of architectural design CPS. Possibly, demonstration of experiments to students at the junction of CE and physics, which makes it possible to create various interdisciplinary courses, demonstration to CE specialists of methods for measuring the thermal properties of materials, and to physicists of the basics of data processing and the specifics of constructing CPS for conducting physical experiments.

As a controller for automating thermophysical measurements, we propose using the SDK-1.1M training laboratory bench [8], as well as a special expansion module for thermophysical measurements TFK-4.0. The module is made in the Arduino form factor, since the SDK-1.1M has an Arduino-compatible connector. TFK-4.0 contains a 24-bit Sigma-Delta ADC based on the AD7194 chip. The module is equipped with connectors for connecting 4 thermocouples with a temperature range from -150 to + 400 with an EMF of about 40 V. It is also possible to connect resistance thermometers and remote digital temperature sensors DS18b20. The logic analyzer is integrated into the board for debugging purposes. This module will be interesting for students of the School of Biotechnology and Cryogenic Systems as the module provides the ability to conduct high-precision measurements, and students of the Department of Software Engineering and Computer Systems, who can learn how to work with the ADC, as well as develop communication protocols with the DS18b20.

DS18b20 temperature sensors are connected directly to the SDK-1.1M microcontroller, thermocouples and resistance thermometers are connected to the ADC chip with an integrated SPI interface. All the main communication interfaces SDK-1.1M (SPI, I2C, UART), including the software-based OneWire protocol, are connected to the built-in logic analyzer for more convenient debugging. The architecture of the module is shown in Picture 3.

A key component of the expansion module is the AD7194 chip, a low noise, highly integrated system for precision measurement systems. At the heart of the device is a 24-bit - ADC, built-in PGA, which allows low-amplitude signals to be fed to the microcircuit inputs. The microcircuit inputs can be configured as eight differential or sixteen pseudo differential. Functional diagram of the AD7194 is shown in Picture 4.

The first software prototype was developed, with the development of which difficulties began. The implementation of native software for Windows (Windows Forms and WPF) and Android (Java / Kotlin) was abandoned for several reasons:

- The costs of programming native desktop applications are quite high in the face of changing system requirements;
- We need cross-platform. students often come to classes with their laptops, many Linux and Mac OS X. Users have mobile phones on Android and iOS. Implementing and supporting native applications for all platforms is complex and expensive;
- In connection with the beginning of the development of a system of heterogeneous modeling of CFS, it turned out to be very useful to implement training software in the form of web services;

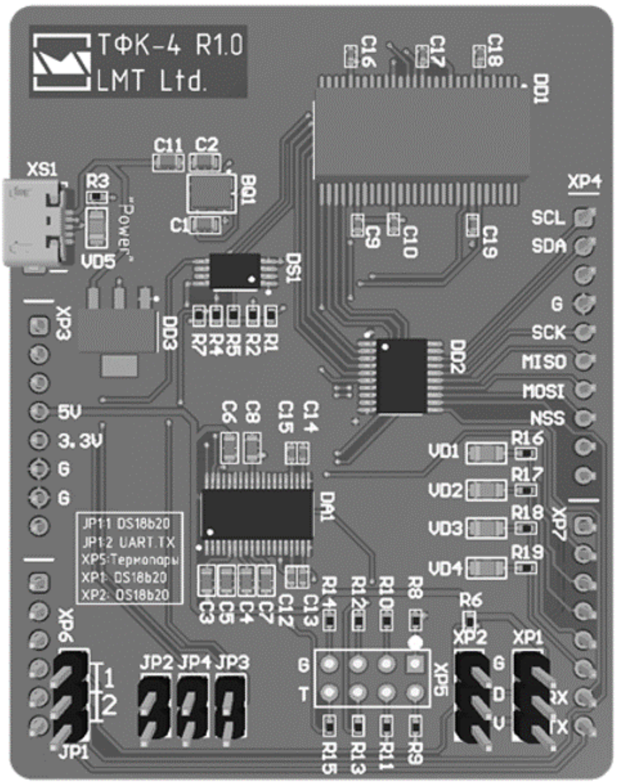

Fig. 2. Picture. 2 TFK-4.0 Module

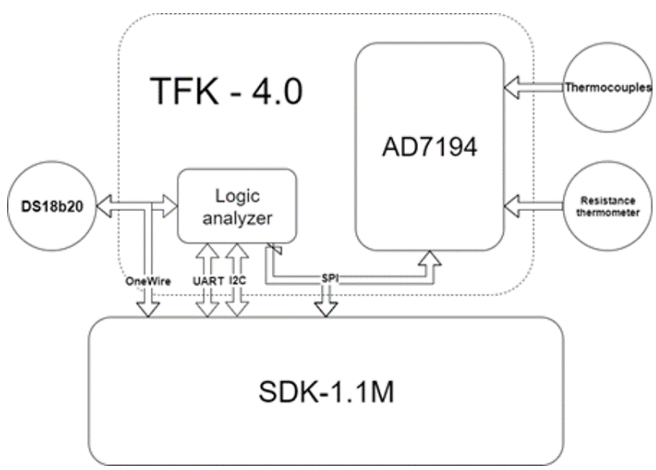

Fig. 3. Picture. 3 Architecture of TFK-4.0

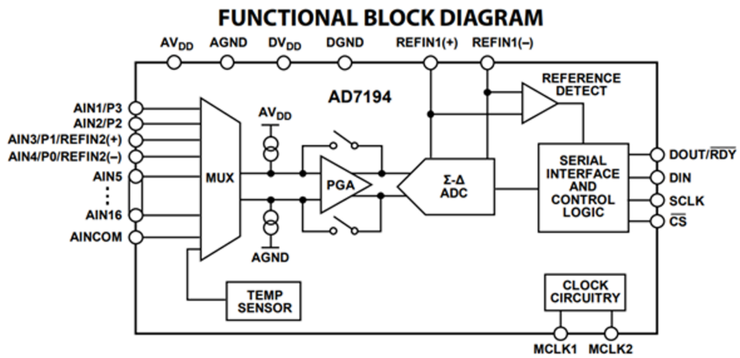

Fig. 4. Picture. 4 Functional block diagram of AD7194

– Native desktop programs are gradually becoming obsolete and superseded by Web technologies.

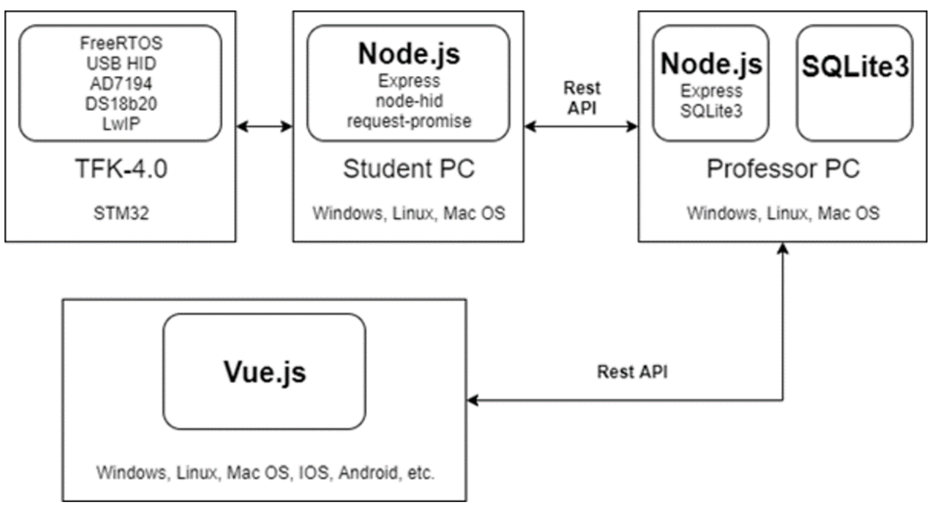

Fig. 5. Picture. 5 Software architecture

An analysis of technologic stacks was carried out, in which the main criteria were capabilities, entry threshold, development speed, prevalence, support and prospects. As a result, the software for TFK-4.0 consists of a program for SDK-1.1M, a program for a student and teacher. The following technologies were used.

Program for SDK-1.1M:

– FreeRTOS;
– LwIP;
– USB HID;
– AD7194 driver;
– DS18b20 driver.

Student program:

– Node.js;
– Rest API..

Professor program:

– Node.js;
– Rest API;
– SQLite3.

Javascript was chosen as the main language of the top level, Node.js. was chosen as the platform for building the backend. The frontend is implemented using the Vue.js. framework. To implement the embedded software, the C language is used for the STM32 + HAL + FreeRTOS platform. Currently, this hardware and software is in the implementation phase.

Any condensed (solid and liquid) substances and materials of inorganic and organic nature (heat insulators, polymers, food products, semiconductors, metals, etc.) can be used as the objects under study.

An automated training laboratory stand is designed to equip research and educational laboratories of higher educational institutions with a heat engineering profile. According to its operational and metrological properties, this automated complex may also be of interest in various fields of scientific research and industries for certification of thermal characteristics of products.

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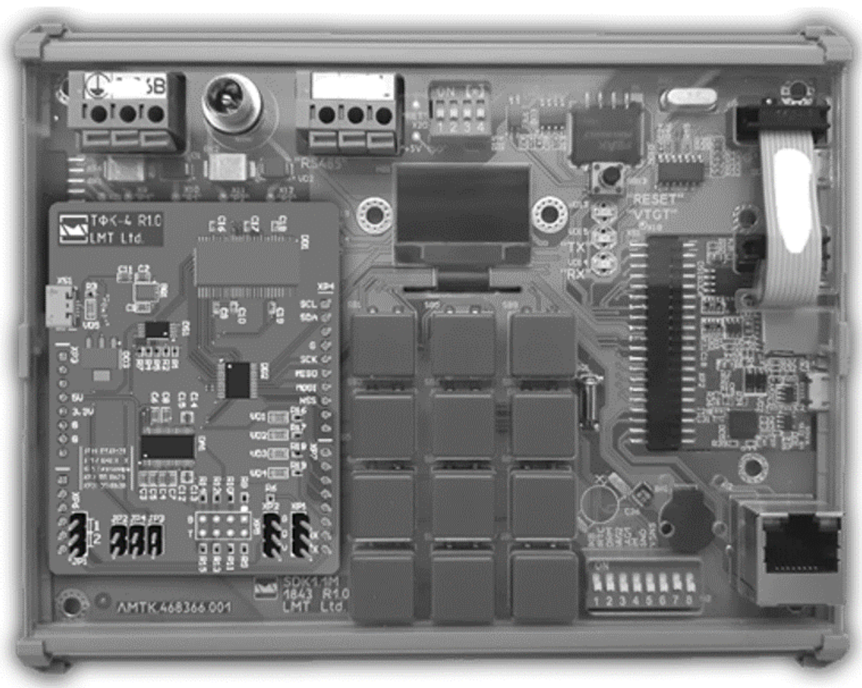

Fig. 6. Picture. 6 SDK-1.1M with TFK-4.0 module

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