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Multi-level computer systems for automation of scientific research

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Abstract. The article is devoted to multi-level computer systems used to automate scientific research. The authors show that to automate scientific research, it is important to correctly formulate the composition of hardware and software for experimental installations and test benches. Automation means include structural devices and measuring instruments. Correct functioning of the hardware and software complex ensures the acquisition of new characteristics. The analysis of the values of these characteristics depends directly on the metrological equipment, as well as on computer processing of the measurement results. The automation of scientific research can significantly increase the objectivity and reliability of the results of experimental research, since during research a series of tests are performed. Thus, the computer technologies used make it possible to organize hardware and software support for the automation of scientific research, which ensures, over a fixed period of time, the minimization of measurement errors with limited time resources. Moreover, during this period of time, due to automation, a sufficient amount of data is collected to prove the reliability of the results obtained. This is achieved through the construction of multi-level automation systems with coordination of the work of multiple objects distributed geographically.

1 Introduction

The process of organizing and conducting fundamental and applied research is aimed at obtaining specific results, which in turn presupposes the establishment of general requirements for the organization of scientific research work (R&D); functions of the main participants in research work, the order of their interaction; requirements for the order of implementation and acceptance of individual stages and research work as a whole; the procedure for the development, coordination and approval of documents during the organization and implementation of research work; the procedure for implementing and using the results of completed research [1].

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In accordance with the developed research program, expressed by a set of regulations characterizing the modes of the technological process implemented in the experimental installation, the task arises of constructing an automated scientific research system, or, as a special case, constructing an automated technological process control system.

Modern approaches to the automation of technological control objects (automation objects) and the technological processes implemented on them provide for the formation of multi-level control systems [2-4].

The first level of technological means includes instruments and equipment for monitoring and regulation (sensors of process parameters, converters, regulators, starting and switching equipment, microprocessor controllers for data collection and processing).

Primary sensors that perceive the effects of measured and controlled quantities, regulatory bodies are installed directly on the process equipment and pipelines of the control object. Converters and starting equipment can be installed both locally and on switchboards.

Sensors transmit information about the state of process parameters to controllers.

According to a pre-programmed program (algorithm), controllers control the actuators of regulatory bodies. Microprocessor controllers are united by a central workstation into a single local area network and, after initial loading, function autonomously, but can, on demand (request), transmit and receive information from the upper level (second level).

The second level includes a central workstation (PC), which implements the functions of monitoring the operation and condition of the main equipment, selecting a control mode, logical processing of electrical signals, displaying information about the state of technological objects on the monitor screen, accumulating and transmitting data.

2 Materials and methods

In general, the automated system provides for the following types of control:

- supervisory (use of a central workstation to influence regulatory authorities, to start and stop equipment, regulate installations, display and store information about technological parameters);
- manual (remote control from the remote control);
- automatic (use of microprocessor controllers as direct monitoring and control elements).

The following types of support can act as computing systems for scientific research: technical, metrological, information and software.

The target functionality of the automated process control system is determined by the hardware and software of the system. The assigned tasks also depend on what class the system belongs to. For a local or distributed system, the hardware used may differ significantly. In local systems, simple hard logic circuit devices can be used. Distributed systems use both programmable logic controllers and industrial computers. Often the system structure is hybrid in nature, which leads to the use of combined hardware and software.

3 Results and discussion

3.1 Industrial personal computers

The existing models of industrial personal computers (IPC) are developed taking into account the requirements for noise immunity and reliable operation in industrial applications [5]. The information and measurement functionality of IPC is focused on collecting, processing and archiving data. The main tasks that they solve as part of automation systems include monitoring and control tasks, as well as visualization of the progress of ongoing technological processes and the state of equipment (Figure 1).

a)

b)

c)

Fig. 1. IPC: a) rack-mount design; b) for building embedded computer control and visualization systems; c) block execution.

3.2 PC-compatible industrial controllers (SOFTPLC)

PC-compatible industrial controllers (SOFTPLC) (Figure 4), unlike programmable controllers (PLCs), have many programmable functions in addition to those implemented in hardware [6].

a)

b)

c)

d)

Fig. 2. SoftPLC: a) compact design; b), c) a single structural block; d) operator panel.

3.3 Programmable Logic Controllers (PLC)

3.3.1 Communication

Controllers of this type have an open architecture based on the operating system, which facilitates their integration into vertically integrated development environments (Figure 3). We note the following characteristics and features of the PLC:

1. The controllers have powerful hardware resources: a high-speed processor and a large amount of operational (SDRAM) and non-volatile (DataFlash) memory.

a)

b)

c)

Fig. 3. PLC: a) communication; b) panel, c) block type.

2. The presence of USB-Host ports allows you to connect various devices to the controllers:
   - to organize communication with external equipment (GSM/GPRS modems, WI-FI gateways);
   - for connecting external data storage devices (USB-Flash).
3. The presence of a built-in card reader allows you to expand the non-volatile (DataFlash) memory of the controller up to 2 GB.
4. Built-in real time clock.
5. The ability to work using any non-standard protocol using any of the interfaces, which allows you to connect devices with non-standard protocols (electricity, gas, water meters, barcode readers, etc.).
6. Possibility of programming controllers in the professional, widespread environment CODESYS v3.5, which is most compliant with the IEC 61131 standard.
7. A set of ready-made software modules provided free of charge.
8. Built-in Linux operating system.
9. 1 x Ethernet.
10. 2 x RS-232/RS-485 and 2 x RS-232 for connecting various equipment.
11. 2 x USB for connecting external storage devices.
12. Availability of a built-in card reader for connecting SD cards up to 2 GB.

Panel PLCs. Controllers of this type have the following distinctive features:

- Increased performance, 600MHz processor.

- Combination of PLC functions and graphical operator panel in one housing.

Development of visualization programs and control algorithms in a unified programming environment:

- Touch screen controls.
- Additional control buttons with LED indication.
- Software switching of operating modes of universal RS-232/RS-485 interfaces.
- Detachable terminals for RS-485 and CAN.
- Indication of the status of exchange via serial interfaces on the front panel.
- Built-in Ethernet interface.
- Built-in Linux operating system.
- Full modem RS-232 port.
- Expanded number of interfaces.
- Support for ModBus, ARIES, CAN-open exchange protocols.
- Ability to work directly with controller ports to connect non-standard devices.
- The controller has a built-in clock to create control systems based on real time.
- Availability of a large amount of Flash memory, expandable on an SD card for data archiving.
- Expansion of the number of input/output points is carried out by connecting external input/output modules via any of the built-in interfaces.

Application area:

- HVAC systems.
- In the housing and communal services sector (individual heating points, central heating points).
- In automated control systems of water utilities.
- To control climate control equipment.
- In the field of production of building materials.
- On transport.
- Optimal for building distributed control and dispatch systems using both wired and wireless technologies.

3.3.2 Block type PLC

Let us consider the controller with HMI for local automation systems. The main areas of ARIES PLC63 are boiler houses, small installations. Let's note the following main elements of the controller:

- Two-line character-synthesizing display.
- Availability of discrete inputs/outputs on board.
- Custom modifications with a choice of discrete/analog outputs.
- Built-in RS-485, RS-232 interfaces.
- Built-in real time clock.
- Supports ARIES, Modbus RTU, Modbus ASCII, GateWay protocols.

3.4 Programmable relay

3.4.1 Discrete local systems

This equipment is suitable for local automation tasks with a linear or slightly branched control algorithm, for example (see Figure 4):

- Access control and relay protection systems;
- Implementation of automatic transfer switches;
- Management of external and internal lighting, shop window lighting;
- Control of technological equipment (pumps, fans, compressors, presses);
- Implementation of conveyor systems;
- Control of lifts, parking machines, etc.;
- Up to 12 discrete inputs;
- Power supply from both 24V and 220V;
- Internal timer;
- Real time clock (optional);
- Extended operating temperature ranges -20...+55 ºC;
- Compact housing for DIN rail mounting;
- Work in the Modbus-Slave network (with PR-MI485).

3.4.2 Distributed systems

A programmable relay is convenient to use for solving problems of water treatment, water purification and control of small pumping groups for local automation.

a) b)

Fig. 4. Programmable relay: a) for discrete local systems; b) with indication for distributed systems.

Each interface can operate in both Master and Slave modes (ModBus RTU/ASCII).

Exchange on each interface is carried out independently of each other.

The interfaces are made in the form of boards that are installed (independently) into the mounting sockets of the programmable relay housing, and do not take up additional space on the DIN rail [7].

3.5 Microcontrollers

In tasks of automation of technological processes, microcontrollers are used as embedded systems and perform certain functions of a ready-made system, including as part of the above-mentioned devices and solutions.

3.5.1 Human-machine interface (HMI)

Includes electronics for transmitting signals and monitoring the status of industrial automated equipment. This is a very broad class of devices, containing a variety of solutions, from the simplest LED status indicator to a 20-inch LCD panel with touch input support. HMI systems are subject to requirements such as mechanical reliability, resistance to moisture and dust, the ability to operate in a wide temperature range, and in some cases, communications security. Such systems must have degrees of protection IP65, IP67 and IP68.

LED indicators and mechanical switches are the most common HMI solutions in the industry.

Hardware security products maintain the integrity of firmware by protecting it from unauthorized changes, ensuring uninterrupted and reliable operation.

3.5.2 Sensors

Industrial sensors contain the electronics necessary to detect, position or identify an object or rotating axis in an automated system. Many different technologies are used, such as inductive, magnetoresistive, capacitive, optical, pressure and ultrasonic. The following requirements apply to industrial sensors:

- availability of non-volatile memory for calibration data;
- small size of the printed circuit board;
- accuracy of analog measurements;
- support for arithmetic operations for signal normalization;
- support for hardware solutions to ensure secure identification and organization of secure communication channels.

Control and measuring instruments (instruments). Active mode power consumption is critical for this type of product because most field instrumentation is powered via a 4 to 20 mA current loop interface, severely limiting the available power resources for the electronics. Often such instrumentation is operated in hazardous areas and cannot store energy.

Based on the considered composition and characteristics, the following features and advantages can be formulated:

- Atmel 32-bit microcontrollers are capable of operating at low voltages as low as 1.62 V and power consumption as low as 1 mW/DMIPS.
- In process instrumentation, microcontrollers often operate at reduced frequencies to minimize power consumption. Atmel developers have optimized flash memory access operations to read data under such conditions.
- Atmel AVR 32-bit microcontrollers and SAM3 family devices based on ARM® Cortex™-M3 processors use a modern, efficient RISC architecture that supports complex signal processing.
- Built-in digital signal processing (MAC, saturation arithmetic) and floating-point functions.
- Security checks of on-board flash memory. Atmel 32-bit microcontrollers support up to 512 KB of on-chip flash memory.
- Atmel microcontrollers are equipped with specialized hardware mechanisms to implement the IEC 61508 security standard. Learn more about the security features of Atmel microcontrollers.
- Wireless communications are an attractive solution for industrial sites with instruments distributed over a large area of the facility. Atmel's line of microcontroller products for wireless applications provides the necessary hardware

platform to create products compatible with the popular HART wireless protocol. Atmel RF solutions provide best-in-class performance to ensure maximum range and improve reliability of RF communications while maintaining high data rates.

- The Atmel Crypto Authentication™ family of security hardware products are easy-to-implement, cost-effective, low-power solutions designed to secure communications with process control tools [8].

3.6 SCADA systems

Today, SCADA class systems are being developed and implemented - data collection and supervisory control systems, which represent information, software and, partly, mathematical and metrological support for automated process control systems (Figure 5; source: https://simplight.ru/).

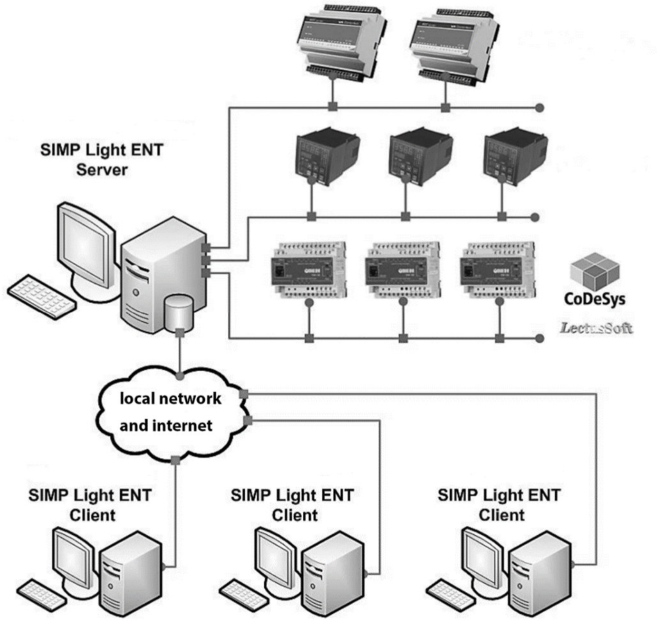

Fig. 5. SCADA system.

The main functionality of SCADA Simp Light is presented below with a description of the following blocks of the system.

1. Drivers (input/output): built-in Modbus TCP/RTU driver (network and COM port); OPC DA (live data); OPC HDA (archive data); built-in Modbus Slave TCP (SCADA as a controller); freely programmable HTTP/S.
2. Alert system: color alert on mnemonic diagrams; sound notification; EMAIL alerts; SMS notification; log of accidents and events; notifications in Telegram.
3. Reports: reporting system - visual report editor; export to EXCEL; generating arbitrary EXCEL files from a script; generation of arbitrary text files.
4. Logic - scripts: built-in script engine (Pascal, C supported); schedules, conditions, mathematical and logical operations; working with bits; working with databases.
5. Graphics: graphics gallery; large selection of indicators and components; support for multiple monitors; network clients (mnemonics, trends, history); WEB-view (tabular view only).

6. Client – server architecture: network clients (mnemonics, trends, history); WEB-view (tabular view only); authorization and access rights system.
7. Data storage system: reliable database of its own format; data replication to third-party databases (MSSQL, mySQL); access to data from scripts; There is no limit on archive depth.
8. Integration: Modbus Slave; SQL ODBC support; interaction via HTTP/S; text files.
9. Mobile devices: own application for remote control of technological objects.
10. Video control: displaying the video stream from IP Cameras on mnemonic diagrams.

SCADA system components:

– Channel editor: to configure communication with equipment via MODBUS or OPC; to create scripts; for setting up real and virtual tag channels; to configure authorization.
– Mnemonic diagram editor: for creating and editing mnemonic diagrams - graphic screens; for testing mnemonic circuits.
– Monitor polls devices and controllers; displays mnemonic diagrams; saves values to the database; executes scripts; registers emergency events.
– Mobile client: for remote control of industrial and home automation systems.
– Graph viewer: for plotting graphs and visual analysis of measured parameters.
– Report generator: to generate reports on the collected data.
– Project Manager: for managing SIMP Light user projects [9].

4 Conclusion

Improving the process of conducting experimental research is associated, first of all, with increasing metrological support and the introduction of measuring instruments, automation of the measurement process by building multi-level automated control systems. All this helps to increase the productivity of the researcher by performing a number of tasks using automated devices, such as recording measurement results, various switching during the study, monitoring the condition of the object and measurement system; reliability of the results, which is achieved by stabilizing the state of the object and the measurement system, automatic calibration of the measurement system, simultaneous measurement of parameters for each fixed state of the research object; increasing the efficiency of installations; ensuring fast data processing and control over the progress of the experiment [10].

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