Functional Classification And Structural Analysis Of Technical Means For Automation Systems

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Abstract: *This report presents a comprehensive analysis of the technical means for automation used in automatic control systems. The study examines the fundamental concepts of automation devices and proposes a systematic classification based on functional purpose, dynamic properties, energy form, and methods of interconnection. The functional structure of an automatic control system is analyzed in detail, emphasizing the interaction between measurement, information processing, and actuation elements. Special attention is paid to unified signals and standardization, which ensure compatibility and reliable operation of automation systems. The presented analysis provides a theoretical foundation for understanding, designing, and implementing modern automation systems in industrial technological processes.*

Keywords: *automation systems, technical means for automation, automatic control, functional classification, unified signals, control structures*

1. INTRODUCTION

Automation is a fundamental component of modern industrial and technological development. The increasing complexity of technological processes requires reliable, precise, and efficient control methods that minimize human intervention while ensuring safety and productivity. Automatic control systems fulfill these requirements by using a wide range of technical means that measure process variables, process information, and apply control actions to technological objects. Due to the diversity of automation devices and their different operating principles, a systematic classification of the technical means for automation is essential. Such a classification facilitates system design, analysis, maintenance, and interoperability between different components. This report aims to present the main classification criteria of technical means for automation and to analyze their functional roles within the structure of automatic control systems. Figure 1 shows the automation system cycle.



Fig. 1. Automation System Cycle

The study focuses on the logical and functional relationships between system elements rather than on specific hardware implementations. In addition to improving efficiency and productivity, automation systems significantly enhance the stability and repeatability of technological processes. By reducing the influence of human factors, such systems minimize errors caused by subjective decisions, fatigue, or delayed reactions.

This is particularly important in continuous and high-speed industrial processes, where even small deviations from the desired operating conditions can lead to reduced product quality, increased energy consumption, or equipment damage. Therefore, the application of automatic control systems based on properly selected technical means for automation is a prerequisite for achieving consistent and optimal process performance in modern industry.[4]

2. BASIC CONCEPTS OF TECHNICAL MEANS FOR AUTOMATION

Technical means for automation represent a set of devices, instruments, and systems used to control technological processes so that they operate according to a predefined desired behavior. In a broad sense, technical means for automation include all devices used for monitoring, controlling, and regulating processes, regardless of whether a human operator is directly involved. In a narrower sense, they refer specifically to devices that operate within automatic control systems without continuous human intervention.

The primary purpose of technical means for automation is to ensure that the controlled process follows the desired trajectory by continuously comparing the actual state of the process with a predefined reference value. To achieve this, information about the process must be acquired, transmitted, processed, and transformed into a suitable control action.

These activities form the basis of the functional structure of any automatic control system. Given the large number and variety of automation devices, their classification based on characteristic features is necessary for effective study and application. The following sections present the main criteria used for classifying techni-

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cal means for automation. From a systems engineering perspective, technical means for automation serve as the interface between the physical technological process and the abstract control algorithms. They enable the transformation of physical quantities such as temperature, pressure, flow rate, or position into information signals that can be processed by control devices. At the same time, they provide the physical realization of control actions by converting control signals into mechanical, electrical, or fluid-based effects. As a result, the performance and reliability of an automatic control system strongly depend on the accuracy, sensitivity, and dynamic behavior of the selected technical means for automation. Figure 2 shows the technical means for automation.[3]

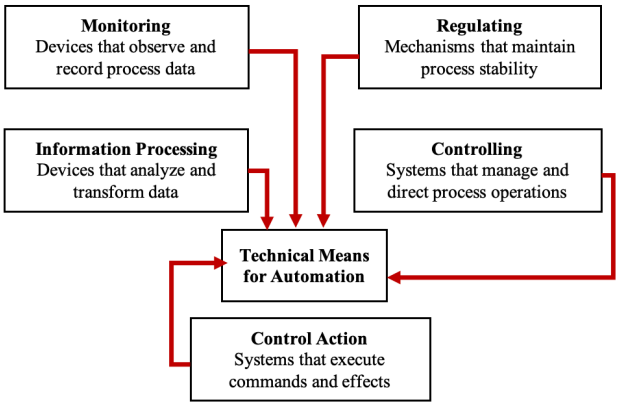


Fig. 2. Technical Means for Automation

3. CLASSIFICATION OF TECHNICAL MEANS FOR AUTOMATION

In order to ensure systematic analysis and practical applicability, technical means for automation are commonly grouped according to specific classification criteria. These criteria reflect the functional role of the devices within the control system, their dynamic behavior, the type of energy they utilize, and the methods used for signal transmission and interconnection. Such a structured classification approach not only simplifies the design and analysis of automation systems but also supports standardization, compatibility, and effective integration of components from different manufacturers.[2]

– **Classification by Functional Purpose**

The functional purpose of technical means for automation is the most important classification criterion, as it directly reflects their role within the automatic control system. Any automatic control system consists of interacting components that collectively ensure the desired behavior of the controlled process. According to their functional purpose, technical means for automation can be divided into three main groups:

- Means for information acquisition and transformation;
- Means for information processing and control signal generation;
- Means for application of the control action.

The first group includes measurement devices that acquire information about the current state of the controlled process. Typically, these devices consist of a sensitive element (sensor) and a transducer that converts the measured physical quantity into a suitable signal. In many cases, the measured information is displayed, recorded, or signaled using indicating devices, which allow for monitoring and diagnostics. The second group is responsible for processing the acquired information and generating an appropriate control action. The central element in this group is the automatic controller (regulator), which compares the desired value of the controlled variable with its actual value and generates a control signal according to a predefined control law. The controller may include summing elements, functional blocks, amplifiers, and adjustment mechanisms that allow tuning of control parameters to match the properties of the controlled object. The third group consists of actuators and regulating elements that apply the generated control signal to the controlled process. Actuators convert the control signal into mechanical motion or another form of physical action, which affects the regulating element. As a result, the flow of energy, mass, or another control variable entering the controlled object is modified, reducing the control error and stabilizing the process. The interaction between these three groups is clearly illustrated by the functional scheme of an automatic control system, where information flows from sensors to the controller and control actions flow from actuators to the controlled object.[6]

– **Classification by Dynamic Properties**

Another important classification criterion for technical means for automation is their dynamic behavior. Dynamic properties describe how input signals are transformed into output signals over time and significantly influence the overall performance of the automatic control system. Based on their dynamic characteristics, technical means for automation can be divided into two main groups:

- Non-inertial (static) devices;
- Inertial (dynamic) devices.

Non-inertial devices are characterized by an almost instantaneous response to changes in input signals. Their transformation time is negligible compared to the dynamics of other system components. As a result, their behavior can be described using static characteristics. These devices can further be classified as linear or nonlinear, depending on whether the relationship between input and output signals follows a linear law. Inertial devices, on the other hand, exhibit a noticeable time delay between changes in input and output signals. Their behavior is described by dynamic models that include time constants and dynamic coefficients. Similar to non-inertial devices, inertial devices can also be linear or nonlinear. Dynamic characteristics are commonly represented using analytical models, transfer functions, or time-domain responses such as step and impulse characteristics. Understanding the dynamic properties of technical means for automation is essential for stability analysis, controller tuning, and overall system optimization.

– **Classification by Energy Form**

Technical means for automation can also be classified according to the physical form of energy they use for operation. This criterion is particularly important for practical implementation and system integration. According to the energy form, automation devices can be divided into:

- Electrical
- Pneumatic
- Hydraulic
- Mechanical
- Other specialized types

Electrical automation devices are the most widely used due to their flexibility, precision, and ease of integration with digital systems. Pneumatic and hydraulic devices are commonly used as actuators, especially in applications requiring high force or robustness in harsh industrial environments. In many practical systems, different types of energy forms are combined to achieve optimal performance.[5]

– **Classification by Signal Type and Interconnection Method**

The method of interconnection between technical means for automation is another essential classification criterion. To ensure effective interaction between system components, information must be transmitted using suitable signals. Signals used in automation systems may be continuous or discrete, electrical or pneumatic, and wired or wireless. Electrical signals are the most common and may include voltage, current, or frequency variations. To ensure compatibility and simplify system integration, standardized signal ranges are widely used. Typical unified electrical signals include continuous voltage ranges (0–1 V, 0–10 V), continuous current ranges (0–5 mA, 0–20 mA, 4–20 mA), and frequency signals. In addition, coded and pulse-modulated signals form the basis of digital automation systems and are particularly suitable for long-distance transmission with high noise immunity. Standardization of signals ensures interoperability between devices from different manufacturers and improves system reliability and scalability. Table 1 show key quantitative parameters.

Table 1. Key Quantitative Parameters for Classification of Technical Means for Automation.

Parameter	Value / Range
Number of functional groups	3
Feedback loops	1
Time constant T	$T > 0$
Voltage signal range	0–10 V
Current signal range	4–20 mA
Frequency signal range	1.5–8 kHz
Pneumatic signal range	20–100 kPa

4. FUNCTIONAL SCHEME OF AN AUTOMATIC CONTROL SYSTEM

The functional scheme of an automatic control system provides a clear representation of the relationships between its components. It illustrates how information about the controlled process is acquired, processed, and transformed into a control action. In a typical functional scheme, the controlled object is connected to measurement devices that generate signals proportional to the controlled variable. These signals are compared with a reference value in the controller, resulting in a control error. Based on the selected control law, the controller generates a control signal that is amplified and applied to the actuator and regulating element. This closed-loop structure ensures continuous correction of the process and reduction of the control error. The functional scheme also provides a basis for evaluating the influence of individual system components on the overall control performance. By analyzing the position and function of each block within the scheme, it becomes possible to identify critical elements that affect stability, accuracy, and response speed. This approach is particularly useful during the design and tuning stages, were modifications to sensors, controllers, or actuators can be assessed in terms of their impact on system behavior. Furthermore, functional schemes facilitate communication between engineers and specialists involved in the development and maintenance of automation systems. They offer a unified and intuitive representation of system structure, which simplifies troubleshooting, modernization, and expansion of existing installations. As automation systems become increasingly complex, the role of functional schemes as a tool for documentation and knowledge transfer becomes even more significant.[1]

– ***Mathematical Description***

To analyze the behavior of an automatic control system presented by the functional scheme, the system can be described using a standard closed-loop mathematical model. The control error $e(t)$ is defined as the difference between the reference input and the measured output:

$$e(t) = r(t) - y(t) \tag{1}$$

where $r(t)$ is the reference (setpoint) signal, and $y(t)$ is the output signal of the controlled object. The controller generates the control signal $u(t)$ based on a proportional control law:

$$u(t) = K_p \times e(t) \tag{2}$$

where K_p is the proportional gain of the controller. The controlled object is approximated by a first-order linear dynamic model with transfer function:

$$G(s) = \frac{1}{Ts + 1} \tag{3}$$

where T is the time constant of the process. The closed-loop transfer function of the system is obtained as:

$$W(s) = \frac{K_p}{Ts + 1 + K_p} \tag{4}$$

– ***Steady-State Error Calculation***

For a step reference input $r(t) = 1$, the steady-state error e_{ss} of the closed-loop system is:

$$e_{ss} = \lim_{s \to 0} \frac{1}{1 + K_p} \tag{5}$$

This expression shows that increasing the proportional gain K_p reduces the steady-state error, improving the accuracy of the automatic control system.

– ***Interpretation within the Functional Scheme***

The presented mathematical model corresponds directly to the functional scheme of the automatic control system. The measuring device provides the feedback signal y(t), the controller processes the error signal e(t), and the actuator applies the control signal u(t) to the controlled object. The mathematical relationships confirm the role of each functional block and demonstrate how system performance depends on controller parameters.[4]

5. COMPARATIVE SIGNAL ORGANIZATION IN AUTOMATIC CONTROL SYSTEMS

In automatic control systems, the organization of signals within the functional structure has a significant influence on system reliability, scalability, and ease of integration. Depending on the applied design approach, signal transmission and processing may rely on non-unified or standardized signal ranges. While both approaches can provide basic functionality, their impact on system compatibility and robustness differs substantially. The comparison between non-standardized and standardized signal organization is not based on experimental measurements but represents a conceptual evaluation derived from accepted engineering principles. Such comparisons are commonly used to illustrate the advantages of standardization in automation system design and to support rational selection of technical means for automation. In conventional automation systems, signal ranges and scaling factors may vary depending on device-specific characteristics. This often leads to additional signal conditioning stages, increased system complexity, and limited interoperability. In contrast, automation systems based on standardized signal organization rely on predefined numerical ranges and normalized relationships, ensuring predictable interaction between functional blocks. The following table 2 and figure 3 presents a structured comparison between these two conceptual approaches. The values represent typical reference levels used for system description and comparison, rather than measured operational results.

Table 2. Conceptual Comparison of Signal Organization in Automatic Control Systems.

Indicator	Non-standardized System	Standardized System
Signal voltage range [V]	0–5	0–10
Signal current range [mA]	0–20	4–20
Signal normalization	Not applied	$-1, +1$
Interfacing stages	Multiple	Minimal
Signal compatibility	Limited	Unified
System scalability	Restricted	Extended

The comparative representation highlights the role of standardized numerical signal ranges in simplifying the functional structure of automatic control systems. By ensuring consistent signal levels across measurement, control, and actuation blocks, standardized systems reduce the need for additional conversion and matching elements. This leads to improved structural clarity and supports modular system design. Such conceptual comparisons are widely used in automation theory to justify the application of unified signals and standardized interfaces, particularly in complex or expandable control systems.[8]

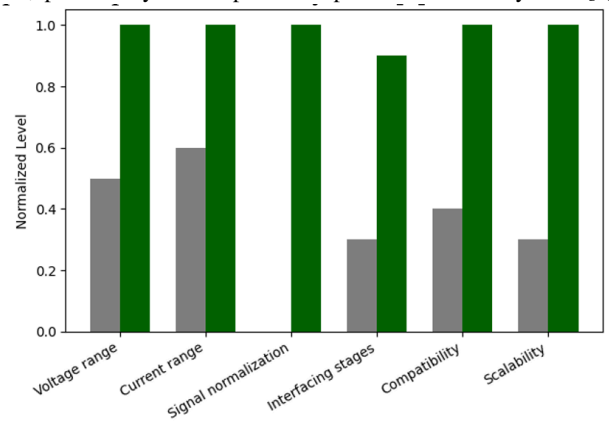


Fig. 3. Comparative representation of signal organization levels in non-standardized and standardized automatic control systems

6. CONCLUSIONS

The graphical representation illustrates a conceptual comparison between non-standardized and standardized signal organization in automatic control systems. The indicators are presented using a normalized scale in order to emphasize relative structural characteristics rather than measured performance data. The comparison shows that standardized signal organization ensures higher compatibility, improved scalability, and reduced need for additional interfacing stages within the functional scheme.[7]

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