DOI: https://doi.org/10.30837/MMP.2023.281

TECHNOLOGY OF USING DIGITAL TWINS IN THE CONTROL OF INDUSTRIAL EQUIPMENT

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The paper describes the technology of program control of the digital twin of the analog signal input module. The proposed program of the digital twin of the analog signal input module in technical means of automation provides ample opportunities for performing various practical tasks in the field of process automation and PLC (programmable logic controller) programming. The task of improving the process of training of professional personnel has been solved by developing a digital twin of the analog signal input module, which makes it possible to study the principles of ADC operation using PLC and technological programming languages.

Introduction

Virtual models of real automation devices are an important tool for distance learning in the process of training specialists to maintain industrial equipment using PLCs and I/O modules. Digital twins of real equipment make it possible to perform practical tasks from any location with Internet access. In general, virtual models have many advantages in teaching technical disciplines and can provide more effective learning and real-world experience.

A digital twin is a software analog of a physical device that simulates the internal processes, technical characteristics, and behavior of a real object under the influence of interference and the environment. An important feature of a digital twin is that it uses information from the sensors of a real device operating in parallel to provide input to it. It can work in both online and offline modes. Further, it is possible to compare the information of the virtual sensors of the digital twin with the sensors of the real device, to identify anomalies and their causes [1–3].

Thus, the creation of virtualization tools for real devices used in industrial automation is a very urgent task.

The aim of the work is to improve the process of training professional personnel by developing a digital twin of the analog signal input module, which makes it possible to study the principles of ADC operation using PLC and technological programming languages.

Automation tools with analog signal input function

In training centers and higher education institutions, various devices are used to study the methods of converting signals from sensors into digital code for its further transmission via industrial networks to a PLC.

Examples of such training models are:

– a model of an industrial controller with an expansion module that allows you to connect analog signals (Fig. 1);

– a separate expansion module for converting analog signals and transmitting digital code over an industrial network using the modbus protocol (Fig. 2).

The module for inputting analog signals can be part of a modular PLC (Fig. 1). In this case, the modules in the PLC are connected via the internal SPI bus. The number and composition of modules can vary depending on the current task.

Thus, the main task is to create a virtual layout that will allow students to explore the principles of analog signal processing by automation. The program under development should provide an opportunity to work out methods for creating technological programs for PLCs using ADC functions remotely, without access to real devices.

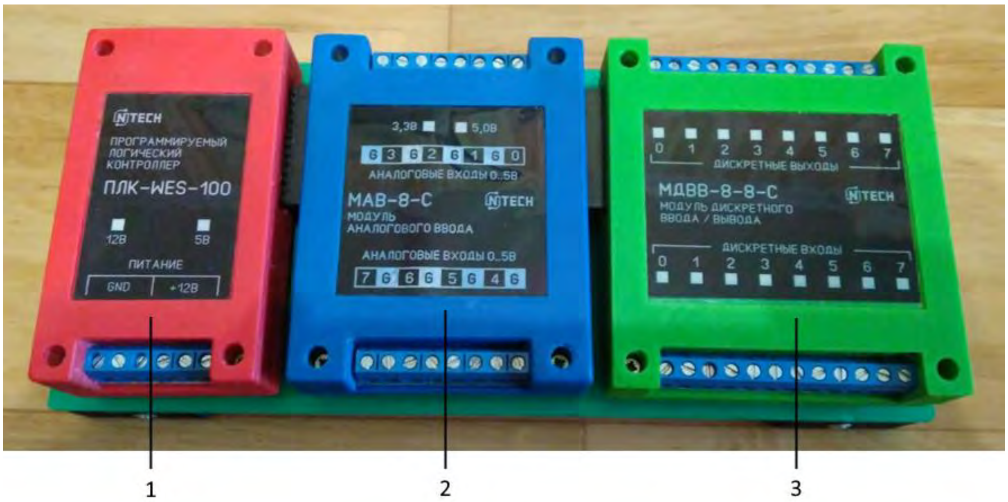

Fig. 1. Exterior of the modular PLC:
1 – central processing unit based on the Raspberry mini-PC;
2 – analog input module; 3 – discrete I/O module

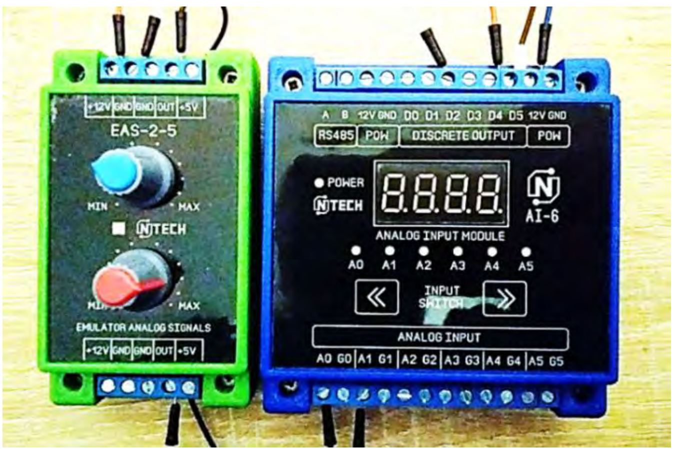

Fig. 2. Expansion module for converting analog signals

Creating an architecture for combining a digital twin with an IDE for developing technological programs for PLCs

Fig. 3 shows the architecture of combining a digital twin with an IDE for developing technological programs for PLC. The virtual laboratory work is aimed at studying the principles of converting analog signals from sensors into digital code to enable its transmission by means of industrial networks to PLCs [4].

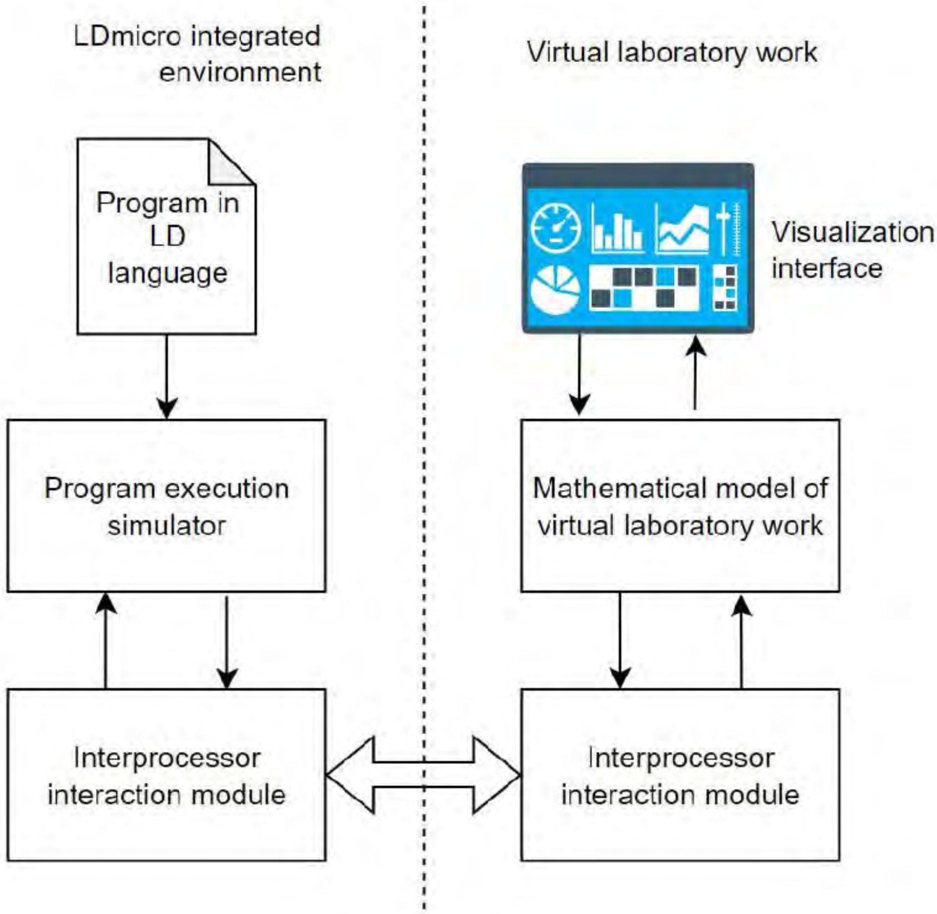

Fig. 3. Architecture of combining a digital twin with IDE development of technological programs for PLC

Using the virtual layout, the ADC parameters are selected and the environment is configured in the form of a digital multi-digit display with dynamic indication.

The digital twin is used to study the

– the principle of reading and converting an analog signal into a digital signal;

– the principle of displaying information by a built-in digital indicator;

– the principle of operation of a resistive voltage divider;

– the principle of measuring and displaying the input voltage, the value of which exceeds the ADC reference voltage;

– the principle of working with ADC by means of a programmable logic controller.

The combination of a digital twin with a PLC occurs at the stage of creating a technological program in the integrated LDmicro environment [5]. LDmicro is a free programming environment designed to create programs for logic circuit controllers (PLCs) in the linear logic language (LADDER). It is designed to simplify the creation of programs for small PLCs, such as controllers used in home, educational, and research purposes [6]. The development environment supports the introduction of a visual representation of the program in the form of a line diagram, which allows users to understand and analyze the operation of programs more easily.

Other features of LDmicro include importing and exporting projects, simulating a program, debugging and debugging programs, creating and editing symbols and libraries, generating documentation, and more.

Thanks to the open source code, it was possible to combine two independent tools: LDmicro and virtual laboratory work. To combine these programs, the technology of interprocessor interaction in the form of Named Pipes is used.

Named Pipes is a mechanism for interacting between processes in an operating system. They allow you to transfer data between processes through a channel that has its own name. This mechanism is a type of interprocess communication (IPC). Named channels can be used to communicate between processes running on the same machine or on different machines in a network. Channels are also used to transfer data, messages, and other objects between processes.

One of the advantages of using named channels is the interaction between processes written in different programming languages and running on different operating systems. They also allow you to transfer large amounts of data, which is not possible through other interaction mechanisms.

The disadvantage of named channels is that they are somewhat slower than other mechanisms of interaction between processes. In addition, the use of named channels requires some additional knowledge and understanding of the mechanisms of working with files and data streams from the programmer.

Description of the basic principle of ADC operation modeling in the digital twin program

When measuring any parameter, such as voltage or temperature, it is advisable to display its real value, not the ADC readings. In this case, it is necessary to convert the ADC readings to the real values of the measured parameter [5, 7].

If the maximum voltage at the ADC input does not exceed the Reference Voltage, then the following formula is used:

$$V = \frac{V_r \times ADC}{ADC_{\max}}, \tag{1}$$

where V_r – reference voltage value, B; ADC – measured value with ADC; $ADC_{\max}$ – the maximum value at the ADC output, which depends on its bit depth.

For example, consider the following input conditions: the reference voltage is 5 V, the ADC bit depth is 10 bits, and the ADC output is 736.

Let's convert the ADC value to a real voltage. To do this, we determine that the maximum value at the ADC output $ADC_{\max} = 1023$ $\left(2^{10} = 1024\right)$. Thus, by substituting the values in formula (1), we obtain:

$$V = \frac{V_r \times ADC}{ADC_{\max}} = \frac{5 \times 736}{1023} = 3.59 \approx 3.6\,B.$$

In LDmicro, all operations are integer, so to work with floating point numbers, you must first find the integer part and then the fractional part.

This is done as follows. To determine the integer part, it is necessary to use the formula:

$$V_{\text{int}} = \text{int}\left\{\frac{V_r \times ADC}{ADC_{\max}}\right\}, \tag{2}$$

where int – operator for determining the remainder of division.

To determine the fractional part, the following formula is used:

$$V_{\text{mod}} = \text{mod}\left\{\frac{V_r \times ADC}{ADC_{\max}}\right\}, \tag{3}$$

where mod – operator for determining the remainder from division.

Description of the graphical interface of the digital twin

The user interface of the virtual layout "Analog-to-digital converter" is shown in Fig. 4. The upper part of the working window of the program is a separate virtual device "Seven-segment four-digit digital indicator" (Fig. 4, item 1). It can be used both independently and in combination with an analog-to-digital converter.

The lower part (Fig. 4, pos. 2) has the necessary controls to study the methods of inputting analog signals using PLC.

The upper part of the virtual laboratory work "Seven-segment four-bit digital indicator" is designed to display current information by means of PLC and to study methods of organizing dynamic display for working with multi-bit digital indicators.

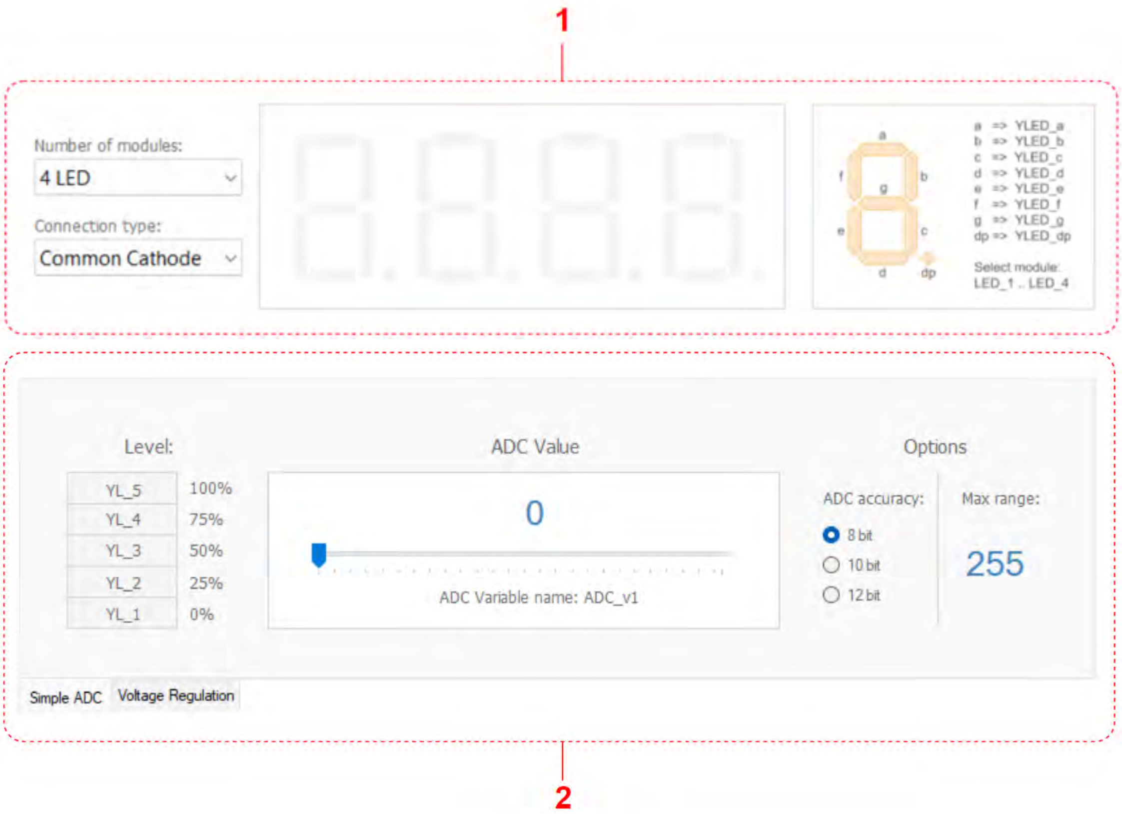

Fig. 4. User interface of the virtual layout "Analog to digital converter"

The main visual upper part of the program is the module of the seven-segment digital indicator 1 (Fig. 5). If you connect to the layout using one of the available interfaces, such as Named Pipes, the digital indicator module will display signs that are a combination of the enabled segments. Each segment can be controlled independently.

Fig. 5. Seven-segment four-digit digital display

Fig. 6 shows an example of the program operation and display of the measured voltage value using a virtual layout [8–10].

The value of the ADC_v1 variable is set by the user using a linear slider and the full range of values can be 0...1023 units. Therefore, in order to correctly display each digit of the specified range, the contents of the ADC_v1 variable must be prepared in advance – divided into four separate variables for thousands, hundreds, tens and units.

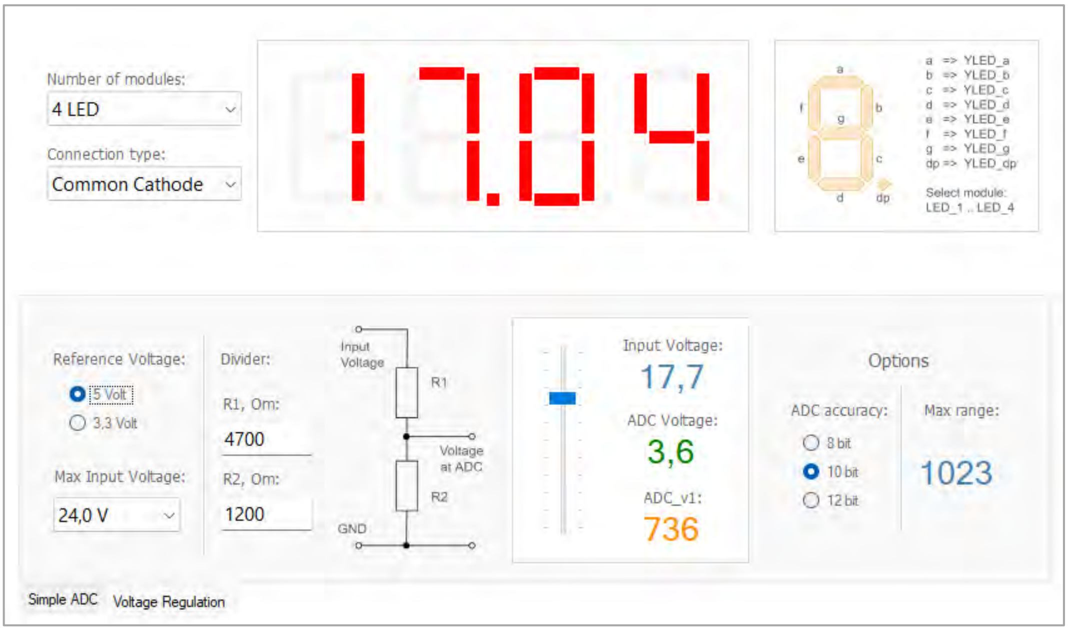

Fig. 6. An example of the program operation and display of the measured voltage value using a virtual layout

To get thousands from a number stored in ADC_v1, divide this number by 1000 and put the integer value of the division into the variable "th". There are two types of division in LDmicro:

– integer division "DIV" (the specified variable stores the integer result of the division);

– division with remainder "MOD" (the specified variable stores the integer value of the remainder of the division).

In the first step, let's perform the division operation "DIV":

{DIV th := ADC_v1 / 1000}.

To get the value of hundreds, you need to determine the remainder of dividing the input variable by 1000:

{MOD th_rem := ADC_v1 % 1000}.

In the third step, we can determine the number of hundreds that is included in the number stored in the variable th_rem:

{DIV hnd := th_rem / 100}.

To determine the number of tens, you need to determine the remainder of dividing the variable th_rem (the remainder after determining the number of thousands) by 100:

{MOD hnd_rem := th_rem % 100}.

The fifth step is to determine the number of tens:

{DIV ten := hnd_rem / 10}.

The last step is to determine the number of units in the number stored in the variable hnd_rem:

{MOD unit := hnd_rem % 10}.

Putting all of these operations together, we get the following LD diagram for converting an input number into four different variables for thousands, hundreds, tens, and units (Fig. 7).

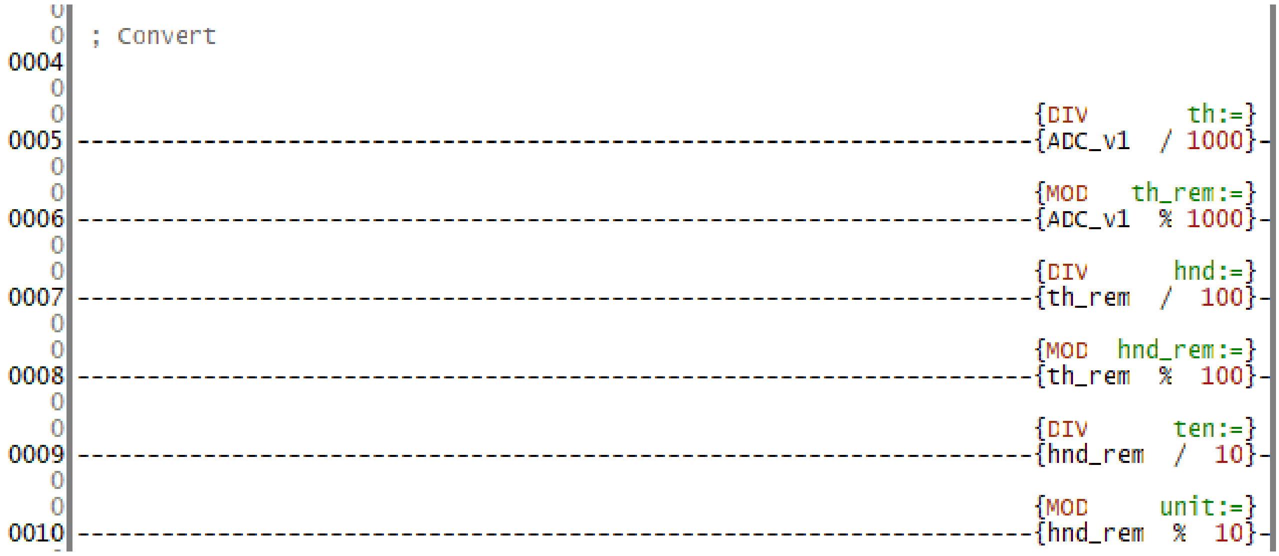

Fig. 7. Operation of converting an input number into four variables for each digit of the indicator

Conclusions

The paper describes the technology of program control of the digital twin of the analog signal input module. The developed program of the digital twin of the analog signal input module in technical means of automation provides ample opportunities for performing various practical tasks in the field of process automation and PLC programming.

A prototype for virtual laboratory work was selected. This device is a model of a modular industrial controller based on the Raspberry PI mini-PC. The purpose of the real device is analyzed and the principle of its operation is described for the further creation of a software implementation of the digital twin. The principle of modeling ADC operation in a virtual program is considered. The graphical interface of the program is described, an example of its operation is given, and the measured voltage value is displayed using a virtual layout.

Thus, the task of improving the process of training professional personnel through the development of a digital twin of the analog signal input module, which makes it possible to study the principles of ADC operation using PLC and technological programming languages, has been fulfilled..

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