Application of Virtualization for Process Control Experiments

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Abstract. The virtualization of the Festo process control teaching platform and the implementation process of extending it with real industry applications are introduced. Taking the heating process of the water tank as an example, the model extraction method of the real object is analyzed in detail, and the model identification problem of the low-order linear control object is solved. Through the introduction of the creation process of the object model on the virtual platform, a feasible way is pointed out for similar applications. On this basis, it is proposed to integrate the teaching platform with the specific industrial industry in the virtualized environment, broaden the breadth of process control teaching, and point out new ideas for building a teaching profession with industry support.

1. Introduction
Digitization wave in the current industrial field is set off an unprecedented change, tracing back to the source, which is the inevitable result of industrial development, IT technology, consumer demand to a certain stage. Personalized product requirements require that industry be more flexible to produce according to higher quality standards, prompting manufacturers to re-examine the entire production cycle and combine new technologies to complete digital transformation, including integrated design and engineering integration, real-time analysis of process data, edge computing and cloud services, and in this complex scheme, process virtualization is undoubtedly the brightest pearl.

At present, in the field of environmental protection, iron and steel manufacturing, cement production line kiln control and other links, the major backbone enterprises have formulated a road map of virtualization programs, some enterprises have already had preliminary results. However, compared with the production field in full swing, the automatic teaching field of process control is only a small load, and few vocational colleges carry out related scientific research and equipment investment. The main reason for this contradiction is that the technical threshold is too high, There are many problems involved, such as equipment model identification, object simulation programming and communication interface with existing control systems. How to solve these problems well based on the existing conditions and seize the first opportunity in the tide of digitization in order to train the teachers and train the talents in the era of real digital chemical industry[1].

As an example, this paper introduces the implementation of virtualization of Festo double-capacity flume experimental platform. On this basis, a brief overview of how to connect the virtual equipment with the specific production process is given.

2. Virtualization Realization of Festo Dual-tank
Festo dual-capacity flume is the first choice experimental device for process control experiments in colleges and universities. Its main features include:

- It is representative and covers the main typical control tasks in process control such as analog/digital quantity display, motor control, valve adjustment, PID control, etc. The controlled physical quantity also covers the most common liquid level, temperature, flow and pressure
• Good cooperation with teaching. The circuits and equipment in the device can be controlled independently and do not affect the final presentation effect, which can make the arrangement of teaching or training more flexible and convenient. In addition, detailed documentation is also convenient for users to organize teaching content[2].

• It is versatile and extendable, and can be compatible with mainstream DCS platforms including Siemens PCS 7 and the latest PCS neo, as well as PLCs of various brands

• The following is a brief introduction to the main process of virtualization implementation.

2.1. Platform Introduction
The Festo dual-capacity flume is composed of two flume about 10 L and the connecting pipe between them. the flume itself is equipped with liquid level switch sensor, radar level meter and temperature sensor. the connecting pipe is equipped with solenoid valve, regulating valve, flow meter and water pump. The related signal cables are connected to the terminal row behind the display board and can be easily connected to the external control system.

Figure 1. Festo double tank

P&ID drawings of the dual tank are shown below, Contains four PID control loops, B102 tank level control LIC101, respectively Pressure control P103, V103 pressure tank Temperature Control TIC104, of B101 Flume Flow control FIC102. at pump outlet More specifically, Pressure control PIC103 and flow control FIC102 are achieved by controlling the speed of the variable frequency pump P101, Here is the need to use the override control strategy. In addition, there are many independent control switch valves and digital / analog monitoring in the device. If necessary, it can also increase the control to realize the water circulation of the B101 tank.

The related control logic is written in the project configuration, and the embedded control template is directly used in the Siemens PCS 7 system CMT which can quickly generate the project program.

Figure 2. P&ID Diagram of Festo Dual-tank
2.2. Model Recognition of Temperature Control Objects

According to the configuration flow of the ordinary project, complete the configuration of the whole project in the PCS 7 environment, download the program to the controller and run. At this time, the whole flume device is controlled by the PCS 7 system, and the process data can be viewed and controlled in the monitoring screen.

The whole process of model recognition can be divided into two steps. First, the response curve of the model is obtained. Based on this raw data, various auxiliary tools are used to identify the specific device model.

The step response method is used to obtain the original data of the model. This method is often used in linear objects, and the experimental objects are the results of field equipment optimization and are typical linear controlled objects. In this example, the online trend control in the PCS 7 is used directly to grab and export the data. As shown in the figure below, a step jump excitation up and down is given near the working point, that is, the set output power of the heater is increased and reduced instantly. Record the water temperature curve. It should be noted that the range selection of the upper and lower jump should follow the following two principles: first, the range of change should fall within the range of linear change of the object. For example, the liquid level of special-shaped flume should be chosen in the range of shape invariant or trend invariant. Second, the range of changes should not be too small. The small range of variation may lead to the low matching degree of the final identified model, especially for some large time-delay objects, such as temperature change and liquid level change of large cross-section vessel. The range of ±10°C is adopted here, and the sampling time is within 20 minutes, which is convenient for experiment.

![Figure 3. Record temperature curve with step jump](image)

After sampling is completed, the data is exported to a '.csv' file, which details the excitation and actual temperature values. In this example, the sampling period is set to 1 second and 948 sets of data are recorded. Since the components of MATLAB have been integrated in Siemens PCS 7, this paper directly calls the built-in tools of PCS 7 to complete model identification.

In the CFC environment, select the PID function block and then select Configure MPC in the menu Edit.(Configure MPC...). This tool was originally used for model identification of the built-in small MPC functional blocks in PCS 7. It can support complex models up to 10x10 (10 manoeuvres and 10 process values with coupling correlation). Naturally, the 1x1 model in this example is also piloted. After opening the tool, the CSV file that has just been exported is loaded by default and distinguishes the amount of manipulation (incentive) from the process value by specifying only two types of quantities:
Figure 4. Importing Data Files into MPC Model Recognition Tool

Click the button "Model approximation" to view the approximate model curve and model transfer function:

Figure 5. Identified model and curve comparison

for curve contrast, the dashed line is the ideal response curve based on the object model function, and the solid line is the real object response curve from the sampled csv file. The better the repetition, the higher the accuracy of the identified model.

At this point, the approximate model of the temperature control object in the experimental device has been obtained:

\[
G(s) = \frac{1.01}{1 + 120s} \quad \text{(1)}
\]

If necessary, the experiment can also be repeated under different step amplitude conditions, and the model with the highest repeatability can be selected from the obtained multiple models.

2.3. Implementation of Object Model under Virtualization Platform

The object model can be used for mathematical research and analysis, but how to match the specific user control program to complete the virtualization of the production process requires the selection of
the appropriate virtualization platform. From the point of view of specific applications, virtualization platforms should have the following basic functions:

- Ability to communicate with DCS or PLC configuration software;
- The ability or solution to communicate with a real controller;
- Provide a wide range of process object models or mathematical models to assist users;

This example adopts Siemens SIMIT platform, which is one of the main pillar products of Siemens digital solution. It can link seamlessly with PCS 7 and import I/O address information directly from the project. Moreover, the Simulation Unit (simulation unit) module can communicate with S7-300/400/1500 and other controllers for simulating IO systems and field devices. A rich basic library is integrated in the SIMIT, which can meet the basic model building, and the fluid library and container library are also used to meet the complex models of chemical industry.

The temperature control object model obtained from the previous analysis is a typical first order object, which can directly call the n order delay object template integrated in the SIMIT:

\[ \frac{dy}{dt} = \frac{1}{T} (x - y) \]  

(2)

The mathematical models of time-delay object templates in time domain are:

\[ \frac{dz_i}{dt} = \frac{1}{T} (z_i - 1 - z_i) \]  

(3)

Laplace inverse transformation is carried out on the analyzed transfer function, and its discrete expression is obtained by Z transformation. Combined with the calculation rules in the template help file, the delay parameters are calculated. Use this parameter to create a new device model in the SIMIT:

The AS01E104” corresponds to the control output of the PID function block in the PCS 7 project and is used as the input of the template after the range conversion[3][4]. The calculation results of the template are also transformed into the range of PLC internal sampling results of 0–27648 or (-27648–27648), and output to "the corresponding AS01TI104", "AS01TI104" is the detection value of the sink temperature in the control system.

All the above implementation processes are based on the control model in the SIMIT. For the primary application requirements, it is simple to use and does not require users to understand too much mathematics and programming. When you need to customize more complex or special objects, SIMIT also provide special tools CTE, Users can use C language to describe object interface parameters and features.
2.4. Switching between Virtual Platform and Real Object
To establish virtualized simulation object of real experimental device, the main goal is to communicate with the role of conventional control system, such as existing real controller, data acquisition server and so on. In addition, the control system can be freely switched between the entity experimental device and the virtual object.

As described above, the simulation model is executed in the SIMIT, Moreover SIMIT provide a virtual controller VC to simulate real S7-400 controllers. Modify the IP address of the existing S7-400CPU (assuming a new IP of 172.16.2.16) in the PCS 7, Former IP address 172.16.2.15), Then the project is downloaded to the virtual controller. At this point the operator system has a fixed communication connection to the virtual controller with a new IP, And based on this exchange of data. All the data in the monitoring system come from the virtual controller and the simulation model behind it. And in the PCS 7 operator system, A user can use a built-in function to modify the IP address of a partner in a communication connection, For communication partners to move from virtual controllers to real S7-400 controllers, Concrete implementation can refer to relevant PCS 7 manual or application document. In this way, the operator can switch between the virtual platform and the real experimental device by clicking the button on the screen.

Another possible application scenario is that the data acquisition server acquires data from both the virtual platform and the real device for data reference and comparison.
2.5. Prospect of Self-learning Function of Virtualization Model

In the real world, the specific equipment is affected by temperature change, deformation, wear and other uncontrollable factors, and its own data model is constantly changing. On the other hand, the process of model recognition is also an approximate approximation process, coupled with the error of sampling data, which will inevitably lead to the inherent defects in the accuracy of the simulation model. In order to ensure and improve the accuracy of the model, the common practice is to train continuously under the premise of large data[5]. In other words, the virtual model can continuously obtain data from the real world, through the internal algorithm, constantly self-learning, so that their own model closer to the real device.

Self-learning algorithms and implementation means are also many, here do not start to repeat. At present, there are no integrated simulation model self-learning components in the mainstream industrial control system, only a small number of model optimization, such as the self-optimization of MPC function blocks implemented by Siemens at the controller level, but the function is limited. And need to occupy a lot of controller operation resources.

3. Extension of Virtualization Objects in Papermaking Industry

Paper industry is a typical process industry, the main process belongs to the category of physical reaction, production continuity requirements are very high, production process is also relatively mature. In the digital tide, although the demand of customized and individualized production is not as urgent as that of the downstream industries of chemical industry such as paint, the challenges of process optimization, quality control and so on have also prompted some conditional papermaking enterprises to start virtualization and digitization attempts.

The whole papermaking line is bounded by a slurry box and can be divided into two parts: pulping and papermaking. As the main control points are liquid level, flow rate and concentration, the control points are scattered, the coupling between the control points except the flow box is weak, and most of them have the characteristics of large hysteresis. The paper-making part mainly controls the parameters of the paper machine around the key parameters of QCS paper products. The main control points are steam pressure, temperature, speed and so on.

Synthesizing the above analysis, the pulping process is a very ideal virtualization application object, and each control loop can obtain the initial object model according to the steps introduced in this paper. At the same time, the material transfer mode between each loop in the process is a slurry pool of various sizes, which is a typical delay object. The time parameters are related to the cross section and shape of the slurry pool, and can be simulated directly by using the model of the container library.

Virtualization in specific industries is not a matter of one day. Device modeling and simulation are only a small step at the beginning. They are the cornerstone of virtualization. Subsequent process modeling requires more expertise. Need paper enterprises and research institutions to work closely together[6]. From the needs of the school virtualization experimental platform, we can introduce more mature complete sets of models under conditions, or cooperate with enterprises to develop them. In this process, we can combine the existing hardware and software foundation to meet the needs of different levels of teaching and scientific research.

4. Epilogue

The virtualization realization process based on Festo dual-tank is an attempt to redevelop the existing laboratory hardware and software equipment, and an important step towards the exploration of virtualization. More importantly, complex model recognition and computation are no longer a roadblock in the whole process. The use of new platforms, such as virtual platform software SIMIT, and the design of overall architecture are the key points to be considered, which is also the core topic in the digital boom.

The introduction of virtualization realization process of a typical temperature object model not only excavates the potential value of existing experimental equipment, but also shortens the transition path from traditional PLC and process control teaching to digitalization. While cultivating talents for the development of digitalized industry, it also opens a new channel for school-enterprise cooperation in the dimension of digitalization.
5. References

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