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Virtual Commissioning of Automated Baijiu Packaging Material Warehousing via Co-Simulation of Virtual Scene and Control Program

Chao Shen[1,a,*], Yu Zhou[1,b]

[1]*Yibin Industry Polytechnic College, Yibin, 644000, China*
[a]*shenchao_edu@163.com*, [b]*3112410945@qq.com*
**Corresponding author*

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Abstract: With the rapid development and continuous iteration of automation technology, the programmable logic controller (PLC) has become a core control unit in the production control of the Baijiu industry. However, most factory technical workers mainly focus on PLC programming and high-cost physical verification, while paying limited attention to co-simulation research combining PLC and Factory I/O. To enrich the portfolio of simulation technology cases, this study conducts simulation research on automated stereoscopic warehouse control for Baijiu packaging materials based on PLC and Factory I/O. First, the control program for the automated stereoscopic warehouse of Baijiu packaging materials is designed based on the Siemens industrial programming environment. This program realizes control functions for both manual and automatic inbound and outbound modes, and the program functions are verified in the S7-PLCSIM V16 simulation environment. Second, the automated stereoscopic warehouse for Baijiu packaging materials and the production line for automatic inbound and outbound operations are constructed based on the Factory I/O three-dimensional (3D) virtual simulation environment. Appropriate parameter configurations are applied to this simulation system to adapt to the logic functions of the control program. Finally, a joint simulation is conducted based on PLC and Factory I/O. The results demonstrate that this method can effectively present the program control logic functions. The simulation environment is demonstrated to be stable and reliable, with a short verification cycle and convenient maintenance and updating. Compared with traditional PLC programming physical verification methods, this approach significantly reduces labor, time, and equipment costs.

1. Introduction

Currently, with the rapid development of modern industrial control technology, the programmable logic controller (PLC) [1,2,10] has become a key driving force in industrial production. For example, in [3], an automatic control system for metal separation and packaging is

designed and implemented. This system mainly consists of a PLC, proximity sensors, motors, and other components. It is capable of saving manual operation time and improving material control accuracy. To enhance product productivity, Thae Thae Ei Aung et al.[4] developed a simple automatic conveyor belt system based on the Kinco K205-16DR PLC. This system is well suited to the actual production requirements of many packaging factories. In the field of logistics and transportation, an automatic logistics warehousing system based on PLC is designed[5]. Practical application demonstrates that this system is safe, reliable, stable, and efficient. Some scholars conduct research on the application of PLC in actual production. For instance, Ding Zhi et al.[6] suggest that PLC technology can effectively reduce product production risks. However, users require corresponding technical training to implement PLC production system operations. To effectively reduce production losses, the OEE model is applied to conduct a detailed analysis of the PLC production line system[7]. The results indicate that this model can effectively address the research objectives. In the food production sector, scholars have already developed a small-scale food packaging system based on PLC[8]. Compared with traditional manual systems, this system can effectively shorten product production time. Furthermore, Ogbaji Okwudili K. et al.[9] examine the effect of product line strategy on the performance of NASCO PLC. They propose that the company needs to further optimize packaging processes and adopt modern technologies to improve product quality.

However, although PLC technology has achieved abundant research results and engineering practical experience in the aforementioned fields, simulation research on automated stereoscopic warehouse control for Baijiu packaging remains relatively scarce[2-5]. In particular, system-level verification research combining virtual simulation platforms is still limited. As an important component of the traditional brewing industry, the Baijiu industry features complex material categories, high inbound and outbound frequencies, and strict storage environment requirements in its packaging material warehousing management. These characteristics impose higher demands on the reliability and flexibility of automated control systems. Therefore, this paper conducts a joint simulation study using PLC and the Factory I/O[11,12] virtual simulation platform. This research aims to explore a low-cost and high-efficiency verification method for automated warehousing system control schemes, and to provide useful technical references and practical guidance for PLC control system design of automated stereoscopic warehouses in the Baijiu industry.

This research mainly encompasses the following three core aspects. The first is the design and development of the PLC control program based on the Siemens TIA Portal programming environment. This program realizes two control modes: manual inbound and outbound operations, and automatic inbound and outbound operations. The second is the modeling and parameter configuration of the automated stereoscopic warehouse and production line based on the Factory I/O three-dimensional (3D) virtual simulation environment. The third is communication integration and joint debugging between the PLC and the simulation platform, completing system-level function verification and performance evaluation.

2. Methodology

2.1. System Framework

This study takes the automated stereoscopic warehouse for Baijiu packaging materials as the research object and employs the Siemens TIA Portal programming platform and Factory I/O 3D virtual simulation software to carry out program design, warehouse modeling, and joint simulation research. The system framework of this study is shown in Figure 1.

As shown in Figure 1, this study selects the Siemens S7-1200 as the central processing unit (CPU) and completes the joint simulation verification of the automated stereoscopic warehouse for

Baijiu packaging materials entirely in the simulation environment. First, the hardware configuration, main program, and subroutines are developed using the Siemens TIA Portal V16 programming platform, and S7-PLCSIM V16 is employed for offline verification of the program functions. In the second place, within the Factory I/O virtual simulation software, one makes use of the drive parameters that belong to the stereoscopic warehouse, and a communication connection is set up with the S7-PLCSIM V16 tool. Moreover, the joint simulation that takes place between the PLC control program and the three-dimensional virtual warehouse is carried out, which makes it possible to watch the working condition of the system and the outcomes of control as they happen in the stereoscopic warehouse setting of Factory I/O.

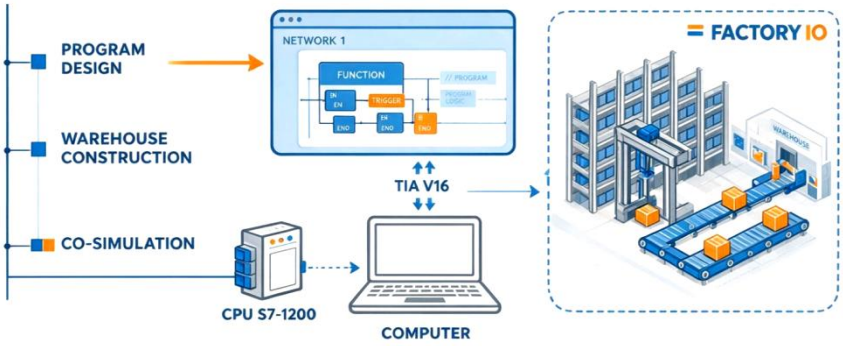


Figure 1: System framework of this study

2.2. PLC Control

In the research presented here, the CPU used for implementation consists of the Siemens S7-1200 PLC series, and the operation of the automated storage facility is managed through the use of two distinct approaches, namely the fully automatic method and the human-operated method. As can be seen from the visual representation provided as Figure 2, the structural outline of the control logic built with the programmable logic controller is made clear to the reader at the end of this description.

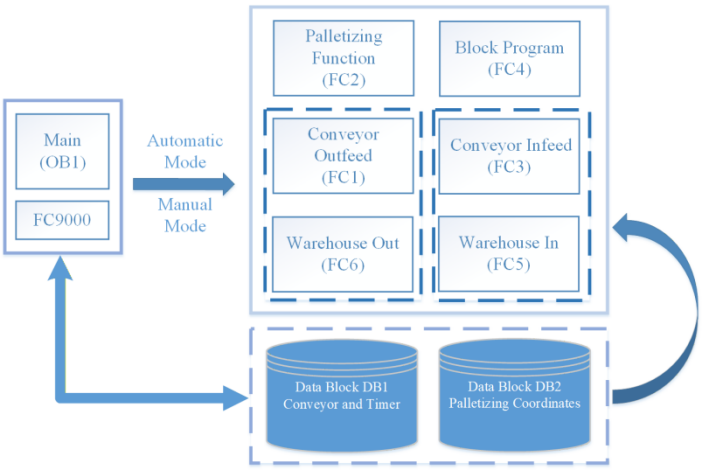


Figure 2: PLC program structure of the automated warehouse

As is demonstrated in Figure 2, the arrangement of the structural parts that make up the PLC program is shown, and this arrangement is primarily made up of three kinds of program units, namely Organization Blocks (OBs), Functions (FCs), and also Data Blocks (DBs). Serving in the role of a connection point that links the PLC operating system with the program written by the user

are the OBs. Within these blocks, the one known as OB1 takes the form of the chief cyclic organization block, and it is run again and again by the CPU in a repeated manner. Taking on the job of a central scheduler, this block thus makes calls to other program units by following a sequence that has been set in advance. Included within the FCs are particular control algorithms or operations of a logical type. In contrast to the OBs, the FCs are not equipped with memory that belongs to them on their own; instead, they make use of the data that is supplied by the block which calls them. Operating as regions for the storage of data on a global level are the DBs, and they give support in the form of unified process data to the main OB1 as well as the different FCs that get invoked by it. By means of this way of designing, a result is reached where there is effective decoupling that is brought about between the management of data and the logic used for control when the program is being executed.

Within the primary organizational block OB1, there exists the incorporation of the communication Function FC9000, and this particular function serves to set up the link for exchanging data between TIA Portal V16 and Factory I/O. In addition to the above, through the repeated invocation of this communication function on a cycle basis inside OB1, the setup attains the joint simulation working state across the PLC and the simulation platform. Moreover, the invocation that repeats on a cycle is carried out at a time interval that stays unchanged, and this is generally in the range of a few milliseconds, thus the keeping of data in sync at real time between the virtual PLC and the warehouse that is simulated is made certain.

In the configuration of the control system, the FC layer makes use of a number of functional components, including Palletizing Function (FC2), Block Program (FC4), Conveyor Outfeed (FC1), Conveyor Infeed (FC3), Warehouse Out (FC6), and Warehouse In (FC5). With the main program taking charge of the scheduling task, these FCs carry out their work in a cooperative manner, and thus the motion control relating to the outbound and inbound handling of packaging boxes is achieved by them together. A particular segment of the control logic, for instance the movement of conveyors or the operation of stacker cranes, is allocated to each FC for processing. Moreover, the adoption of this kind of modular arrangement has the effect of making the tasks of program development and fault finding less difficult.

2.3. Simulation Environment Setup

In the context of this research, a virtual simulation setting has been made use of within the Factory I/O platform to represent an automatic storage facility that deals with the boxes used for Baijiu bottling and packaging. The reason that the Factory I/O system has been selected is that it makes available a lifelike three-dimensional computerized space which can be connected without difficulty to the control code running on PLC devices, and this thus renders it a very appropriate choice for the task of testing control strategies in a virtual manner before real deployment. As has been shown by the visual material presented in Figure 3, the simulated storage building is principally built out of a single stacker crane machine, a unit of racking, and a pair of belt conveyor paths. The racking structure has been set up so that it holds six separate horizontal levels, and on every one of these levels there are nine individual slots for putting items, which together add up to fifty-four places where goods may be kept. Such an arrangement gives a large enough quantity of holding spots to act out the kinds of work seen in actual warehouses, and at the same time it keeps the whole test case small enough that the written control rules can be checked without too much trouble. Moreover, one conveyor for bringing items in and another for taking them out have been placed at the two opposite edges of the racking, and this serves to copy the movements of materials coming in and going out. The described spatial organization therefore creates a typical kind of virtual surroundings where the correctness of the automated warehouse's control instructions can be

confirmed.

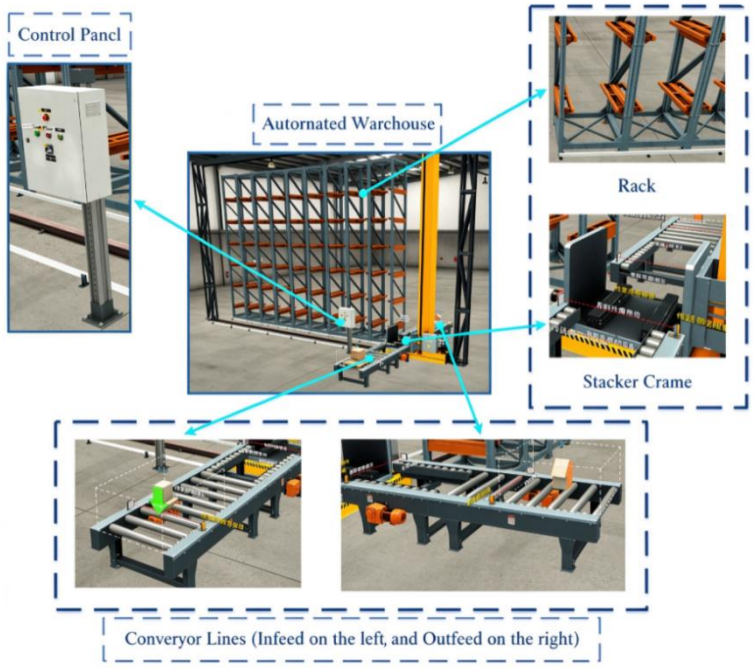


Figure 3: A simulation scenario of the automated warehouse

In the process of material moving into the system, the cartons used for packing are made by the Emitter that is built inside Factory I/O in an automatic manner, and this component acts as the unit that feeds items in. At a set speed, the Emitter is set up to create these cartons, thus copying the unbroken sending of packing supplies seen on a true making line. After that, the conveyor at the input side carries the cartons to the spot where they wait to be taken up. Next, with the use of its fork, the crane made for stacking takes the cartons and puts them in the spots kept for storage that have been chosen. To get to where it should store, the stacking crane goes along the level way and also the up-down way, and its fork moves out then back so as to lift the cartons and set them down. For the step where things leave, the stacking crane takes the packing cartons from the storage spots that are wanted and lays them on the conveyor that brings items out. The cartons are moved by this conveyor by itself to the space where outgoing items are held for a while. By doing all this, the full flow of items coming in and going out is shown again in the made-up setting on screen, and therefore the program that gives commands can be tried when the situation is much like the real working condition.

In the described setting, a control panel is arranged so as to make possible easier interaction between the human operator and the machine. Included within this control panel are a switch for selecting either the manual or the automatic mode, together with a button to begin operations, another to cease them, one for resetting, and also a button that serves for emergency stopping. By means of these various parts, the overall system is given the capability to carry out actions of starting up, bringing to a halt, stopping in an emergency, and returning to a reset state. According to the task that is presently at hand, the operator is permitted by the mode-choosing switch to pick either manual control or automatic control. Moreover, the buttons for starting and for stopping are made use of to commence and to bring an end to the automatic sequence of operations, and additionally the reset button removes the conditions of fault and brings the system back to the state it had at the beginning. As a safety-related provision, the emergency stop button acts to stop all movement at once when some unplanned event takes place. During the phase in which the system is first put into use and adjusted, the manual mode is mainly applied, and this makes easier the setting

of parameters and the checking that the actuators function as intended. At the same time, in this mode the separate actuators, for instance the conveyors and the stacker crane, may each be run on their own, and thus engineers are assisted in examining every single part prior to the running of the complete automatic sequence. Before the stage of co-simulation is reached, this layout allows for testing and for debugging of the control program in a way that is straightforward.

3. Results and Analysis

After completing the program design and simulation scenario construction, TIA Portal and Factory I/O are jointly employed for the co-simulation and debugging of the entire control system. The operational workflow of the PLC program for auto and manual control modes is presented in Figure 4. The main steps of the co-simulation and debugging are summarized in Table I, and partial simulation results are shown in Figure 5.

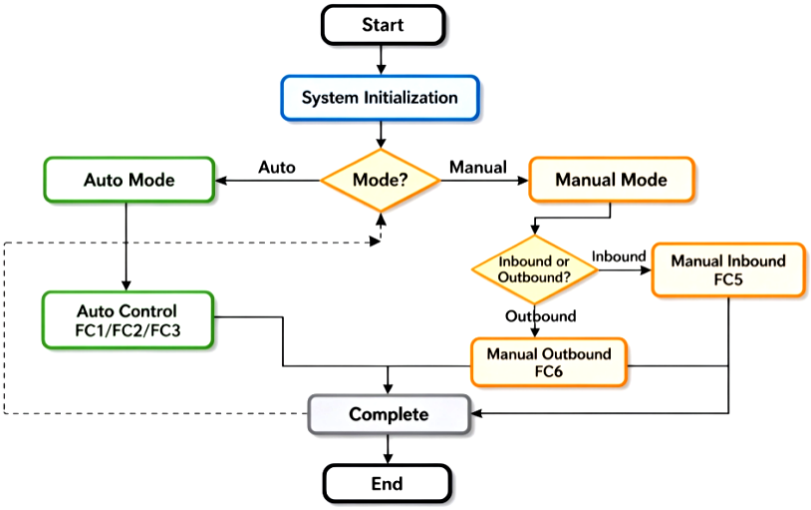


Figure 4: Operational workflow of the PLC program for auto and manual control modes

Table 1: Co-simulation and debugging procedure

Step	Description
Step1	The PLC control program is downloaded to the virtual PLC hardware.
Step2	The virtual simulator S7-PLCSIM is launched in TIA Portal.
Step3	A communication connection with S7-PLCSIM is established in the driver environment of the scenario built in Factory I/O.
Step4	After the communication link is successfully established, the buttons and switches are operated in Factory I/O.
Step5	The simulation phenomena are observed. The process returns to Step 1 to modify the program or the 3D scenario, and Steps 2 to 5 are repeated until the required functionality is achieved.

In accordance with the PLC program workflow that is presented in Figure 4, the operational behavior described below has been shown by the outcomes of the simulation. The mode of operation is decided by the program through the use of the mode selector switch once the system has finished its initial setup, as can be seen from the same figure. In the case that the automatic setting is chosen by the user, the inbound and outbound tasks are then carried out without manual intervention, and this is done by making use of the auto control functions known as FC1, FC2 and FC3, with FC1 handling one part, FC2 taking care of another step, and the third function FC3 also being applied for completion.

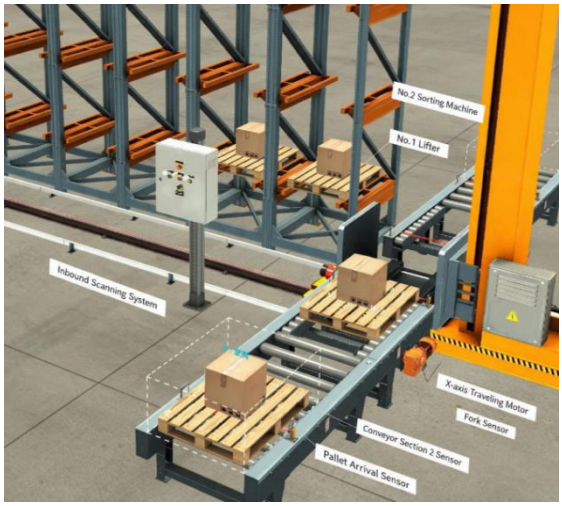


Figure 5: Simulation results of the automated warehouse

Under the automatic inbound function, when the items have been moved to the assigned standby spot on the receiving conveyor, the stacker crane will, through the use of its fork, take hold of the items on its own and then move them to the planned storage position. In addition, the process of putting goods into storage begins at storage location No. 1 as a standard setting, and the first level is given filling priority at the start. Moreover, after the first level has become completely taken up, the equipment will move on to the level above it without manual input, and it does the same thing again. This way of filling one layer and then another keeps going, thus the available spots are all used or the inbound job is finished. The described order makes sure, at the same time, that the area for storage is made use of in a neat and productive way.

Under the automatic outbound setting, the lifting and transfer device makes use of goods by taking them from storage spots following the low-to-high arrangement of their assigned location codes, and after that it puts these items on the belt that carries them out. At the same time, the mentioned belt moves the objects without manual help to the temporary holding space for outgoing shipments. Moreover, this way of taking items out from the smallest to the largest location number is very helpful for keeping the outgoing movement of goods in an organized and expected pattern, and thus it makes the joint operation arrangement between the device and the belt system less complicated.

When set against the conventional single S7-PLCSIM simulation technique that has been used before, the new method that we put forward is able to make use of a way that is closer to real-world industrial situations and also makes it possible to have good control as well as fast fault-finding on the simulated control items. The older way is mostly concerned with checking the correctness of the PLC code inside a setting that is only virtual, and it does not include a true-to-life three-dimensional view of the machine parts. On the other hand, and moreover, the combined simulation approach we suggest brings together the PLC code and a full and detailed 3D model of a storage building made in Factory I/O, so the control steps can be tried out with movement patterns that look real, answers from sensing devices, and the movement of goods. Because of this setup, mistakes in the code and problems in working together can be found early on, and the work of fixing them is clearer and done with less wasted time. Thus, the approach we have described can be seen as a useful and dependable instrument for the testing of automated storage systems before they are built.

4. Conclusions

This paper presents a co-simulation method based on the Siemens S7-1200 PLC and the Factory

I/O virtual simulation platform for the control system verification of an automated Baijiu packaging material warehouse. The PLC control program and the 3D simulation scenario are developed, enabling both manual and automatic inbound and outbound warehouse operations. Simulation results demonstrate that the system correctly executes storage and retrieval tasks, with stable stacker crane motion control and conveyor material handling. Compared with the traditional single S7-PLCSIM simulation approach, the proposed method achieves a more realistic approximation of actual industrial scenarios and provides a low-cost, high-efficiency technical solution for control scheme verification and practical training in the Baijiu industry.

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