Many factories, especially in developing countries, still use old technology and control systems. Some of them are forced to replace at least the control and supervising system in order to increase their productivity. This chapter presents a modern solution for updating the control system of a fodder-producing factory without replacing the field devices or the infrastructure. The automation system was chosen in order to allow correct control of the whole plant, using a single programmable logic controller (PLC). Structure and design of the software project is described. Also, several interesting software solutions for managing special processes such as material extraction and weighing machines calibration are presented. Production quality results and future development are also discussed. In the last part of the chapter some guidelines for automation of a chicken-growing plant are presented.

64.1 Objectives

One of the recent projects we worked on was to design and execute a complete control system for a combined fodder-producing plant. From the start it must be specified that we had to find solutions to command and control the existing machines, and the only things that could be replaced or added were sensors and transducers. Most other devices, such as motors, limit sensors, tension transducers, etc., remained in place. Also 90% of the cable system was retained.

This project had several objectives:

1. Design of the command and control system, taking into account the electrical characteristics of the machines, and the number and type of the electrical signals coming from and going to the system
2. Development of a powerful software system to allow manual control of the whole plant, continuous visualization of all signals and commands, and full automatic control of the production process
3. Real-time communication with personal computers in a local network, enabling managers and other personnel to supervise the production flow and results
4. Ensuring that the total quantity of the final product should not exceed or be less than 5% of the programmed quantity. Also the percentage of every component of the resulted material should be less than 5% different from the calculated recipe.
64.2 Problem Description

A combined fodder plant produces food for industrial grown poultry. This food is a mixture of different types of cereals combined with some concentrated products. Practically, there are three main areas inside the factory:

- The raw material storage area, consisting of several storage bins
- The weighing and mixing area, where the final product is obtained
- The finished-product storage area, consisting of several storage bins, where the resulting product is stored while waiting to be taken to poultry farms.

Part of the plant is presented in Fig. 64.1.

Let us take a brief look at the components of the plant shown in Fig. 64.1:

- There are eight raw-materials storage bins, containing eight different types of cereals.
- From these bins material can be extracted to weighing machine 1, by means of several extractors.
- Weighing machine 1 is used to weigh specific quantities of cereals, with a maximum of 2000 kg supported by the machine. The machine supplies an analog signal in voltage, which we converted to a unified 4–20 mA signal.
- The intermediate tank between weighing machine 1 and the mill is needed because the speed of the mill is lower than the evacuation speed from weighing machine 1.
- The mill is used for milling the cereals.
- The grinding machine is used for grinding the milled cereals.
- The mixing machine is a large tank where the processed cereals are mixed together with some special oil and another component (premix).
- The materials circulate between the machines by means of several transporters and elevators.
- Weighing machines 2 and 3 weigh, respectively, oil and premix extracted from the milling machines. Details will be given later in the chapter.

The production flow can be briefly described as follows:

1. The human operator must establish the quantities for every type of cereal, for oil, and for premix that must be part of the final product. Quantities are determined for only one charge of extraction, because the capacity of the weighing machines is limited. Also the number of charges is specified, in order to produce the whole amount of material wanted.
2. The process starts with extraction of specified quantities of cereals into weighing machine 1.
3. Weighing machine 1 is emptied into the intermediate tank, if some specific conditions are fulfilled. Immediately a new extraction should begin for the next charge.
4. The milling and grinding processes are done automatically; some sensors signal when the corresponding tanks are empty.
5. When the grinding is over, material must be transferred to the mixing machine. After a short time, oil and premix are also loaded into the mixing machine.
6. The mixing process lasts several minutes (a configurable period of time), at the end of which the machine is opened and the finished product is transported to the finished-product storage bins and the charge can be considered ended.

It is necessary to say that, in order to obtain high productivity, another charge must be in course of processing, even if the previous one is not finished. Of course the detailed process implies several constraints and internal conditions, some of which will be discussed later in the chapter.

64.3 Special Issues To Be Solved

One of the first and most difficult parts of the project was to identify all analog and digital signals that must come from and go to the installations. Without proper documentation or an electrical schematic of the plant, this job proved to be extremely time consuming. After analysis, 192 digital inputs, 126 digital outputs, and 12 analog signals were identified, together with the cables connected to them from the previous control system.

Another issue that had to be taken into account was the improper grounding of most of the machines inside the plant, which can cause undesired variation of analog signals. Most of the work regarding this issue was done in software because electrical solutions were not feasible (as they should have been taken into consideration during the design and build of the factory).

During study of the rest of the machines in the plant, some special situations were determined regarding weighing machine 3. Firstly, the four tensions transducers that measured the weight inside the machine were not of the same type. One transducer had been replaced in the past but with a different type, and had a different output electrical tension for the same measured weight compared with the other three transducers. This resulted in nonlinear variation of the unified analog signal with the weight inside the machine. The solution to this problem is described later in the chapter.

The other special effect discovered was that, when weighing machine 3 was opened and premix was transferred to the mixing machine, an air flow developed and pushed up the weighing machine, resulting in incorrect measurement of weight during this process. Stabilization of the signal appears many seconds after extraction stopped. A software solution was chosen for this practical problem also.

64.4 Choosing the Control System

To choose the main control device for such an industrial system correctly, several factors must be taken into consideration, including:

- The number and type of input/output signals
- The complexity of the software that must be developed
- The communication facilities that are requested and can be fulfilled
- The ease of developing a human–machine interface for supervising and commanding the processes
- The budget allocated to this part of the control system.

The solution chosen in this case was the ThinkIO PLC from the German company Kontron. The ThinkIO device is an innovative concept to integrate high-performance personal computer (PC) functionality, fieldbuses, and input/output (I/O) modules. It has a powerful Pentium processor, two Ethernet interfaces, universal serial bus (USB) for keyboard and mouse, and digital visual interface (DVI) for liquid-crystal display.
(LCD) or cathode-ray tube (CRT) displays. For automation applications it can run programs developed in 3S Software Codesys package. Also it can handle hundreds of I/O signals, so it fulfilled the system necessities. Another big advantage of this device is that even the human–machine interface runs on it, so practically you do not need a separate PC to supervise the process or to send manual commands to it. We chose the Linux operating system for this PLC. An object linking and embedding (OLE) process control (OPC) server runs on this PLC so communication with it is easy and reliable. After completing connection of it to the field devices, the next step was to design and develop the software. However, before designing the software solution, there was an important job to do, essential for correct results of the production process.

### 64.5 Calibrating the Weighing Machines

All three weighing machines have some tension sensors that output an electric signal that is (theoretically) proportional to the weight in the machine. Weighing machines 1 and 3 have four sensors, mounted at the four corners of the weighing tank, that output a voltage (0–100 mV) proportional to the force on each sensor. The sum of the four tensions is converted to a current in the range of 0–20 mA and connected to an analogue input of the PLC.

A potential problem could appear if the sensors are not of the same type (different output tension range) or are not mounted perfectly symmetrical. As already described, such a situation occurs for weighing machine 3. The output of one of the sensors had a different tension range to those of the other three sensors.

The standardization procedure implies the determination of the relation between the weight of the weighing machines and the output current of the measurement sensors, practically being the relation between the weight and the engineering units resulting from the analog-to-digital conversion inside the PLC.

To determine this relation, we used 100 standard 20 kg units. Weighing machines 1 and 3 can support up to 2000 kg load. To determine the specified relation, we loaded the machines with consecutive 200 kg weights, until 2000 kg was reached. After that, the weights were removed. 200 kg at a time, until there was no load on the machine. Fortunately, the hysteresis phenomenon was very small and practically did not matter. The characteristic of the machines is shown in Fig. 64.2.

Machine 1 proved to be linear so we adopted (64.1) for calculating the instantaneous weight value

\[
\text{weight}_1 := \frac{\text{adc value} - \text{init value}_1}{\text{scale}_1},
\]

(64.1)

where:

- \( \text{weight}_1 \) is the instant value of the weight (in kg).
- \( \text{adc value} \) is the numerical value obtained by converting the analogue signal (0–20 mA) to 12 bits.
- \( \text{init value}_1 \) is the numerical value obtained from sensors when machine 1 is empty (because the weighing machines have their own weight).
- \( \text{scale}_1 \) is the approximated slope of the line, calculated using the arithmetic average of all DAC units/kg ratios at all the measured points (Fig. 64.2).

Machine 3 had a different behavior because one of the sensors is of a different type to the other three, outputting a tension in a smaller range than the others. The result is that the resulting graph is more of parabolic type. Anyway because determination of the parabolic equation is very difficult, we chose to piecewise-linearize the graph on ten portions. So the formula for one portion reads

\[
\text{weight}_3 := \frac{\text{adc value} - \text{init value}_3}{\text{scale}_3 i},
\]

(64.2)
where:

- weight3 is the instantaneous value of the weight (in kg).
- adc_value is the numerical value obtained by converting the analogue signal (0–20 mA) on 12 bits.
- init_value3 is the numerical value obtained from sensors when machine 1 is empty (because the weighing machines have their own weight).
- scale_3i is the approximated slope of the approximation line on portion i, calculated from the values of start point and end point of the corresponding portion (Fig. 64.2).

- Weighing machine 2 has only one tension sensor so the relation between the weight value and the output tension is linear, so the same formula was used for the whole weighing range (0–120 kg)

\[
\text{weight}_{\text{oil}} := \frac{(\text{can}_{\text{value}} - \text{init}_{\text{oil}})}{\text{scale}_{\text{oil}}}, \quad (64.3)
\]

where the elements of (64.3) have the same meaning as in previous equations.

### 64.6 Management of the Extraction Process

Another delicate process that had to be correctly controlled is the cereals extraction and premix unloading. The cereals are transported from the storage bins with a system of conveyors and elevators and are loaded into weighing machine 1 using several extractors. However, because the end of the extractors is some distance above the weighing machine, there is still some material in the air that will fall into the weighing machine even after the extractor’s motor is stopped.

The quantity falling down in the machine after stopping the extractor depends on various factors:

- Type of cereal
- Quantity desired to be extracted
- Distance from the end of extractor to the weighing machine.

The same considerations apply for unloading the premix in the mixing machine, but the quantity falling after the unloading lid is closed is small. The solution adopted in order to minimize extraction errors was to use some estimated in-air quantity to anticipate the quantity loaded into the machine after the extractor is stopped. In this case the extractor should be stopped before the weighing machine measures the desired quantity. So the estimation (for one material) has an initial value but is adjusted at every extraction with the simple formula

\[
\text{new} \text{estimation} = \text{old} \text{estimation} + 0.5(\text{last extracted quantity} - \text{wanted quantity}), \quad (64.4)
\]

where:

- new estimation is the (in-air) estimated quantity that will be used to determine the moment when the extractor must be stopped for the current extraction.
- old estimation is the estimation used for the previous extraction.
- last extracted quantity is the concrete quantity previously extracted.
- wanted quantity is the ideal quantity that should be extracted.

In this way in three or four extractions the error practically drops below 1 kg. Taking into account that a complete production cycle has tens of extractions, the total extraction error is very small, less than 5%.

After weighing machine 1 is loaded with all types of cereals needed for the current charge, the machine is unloaded completely, when several conditions are fulfilled. Premix and oil quantities are measured somehow differently, i.e., when they are unloaded from the weighing machines into the mixing machine, but the procedure is similar.

### 64.7 Software Design: Theory and Application

The Codesys logical software package was used to develop the control programs. The software project should have had different functions:

- Graphical user interfaces, for configuring the process, for monitoring all the production stages and...
all the factory areas, and for manual command of the installations in the factory

- Automatic accomplishment of planned production
- Implementation of constraints and conditions between different machines
- Sorting and mediation of analogue signals
- Network communication with PCs.

First let us briefly discuss some theoretical approaches regarding the conception of an automation software project. The easiest and most natural type of programming language that should be used for the control part of a program is the sequential function chart. This programming language is supported by the large majority of PLCs producers. Even if this language is not implemented in a PLC and other languages, such as ladder diagrams, must be used, there are algorithms that help the programmer to convert a logical diagram in a ladder diagram. On the other hand, other types of jobs, such as implementation of synchronization and conditioning of events can be done more easily in a ladder diagram type of program. Some examples are shown later in the chapter.

When several industrial processes are be controlled by a single PLC, the best idea is to control every execution device (such as motors, actuators, valves, and so on) separately in a separate logical diagram. If related events for several devices are somehow connected, it is better to develop a single logical diagram for their control. Relationship or synchronization between logical diagrams is achieved by global variables.

### 64.7.1 Project Structure and Important Issues

The structure of the software project is shown in Fig. 64.3.

The idea was to separately control almost every subprocess that takes place during the production flow (extractions, mixing, unloading and so on) [64.1]. Most of the programs are written in sequential function chart (SFC) programming language, the interblocking program is written in the ladder diagram (LD) language and other smaller programs are written in structure text (ST) language. All of these programs run simultaneously in the PLC memory.

Briefly described, the programs have the following functions:

- **Extraction** programs take care of the extraction of each type of cereal, with one program for each type of cereal (written in SFC).

![POUs](image)

**Fig. 64.3** Structure of the software project

- The **interblocking** program takes care of all conditioning between different installations together with automatically stopping some motors when they reach their limits (Fig. 64.4); for example, one elevator cannot be started if a connected transporter was not previously started. The program is written in LD language because it must check all the conditions at every PLC cycle.
- **Loadxxx** programs manage the communication between the PLC and PC (written in SFC).
- The **mixing** program controls the necessary timing needed for the mixing process of the materials.
- The **extraction_supervisor** program supervises the extractions programs. It decides if and when an extraction should start.

Other programs manage the loading and unloading of oil and premix, calculate the average values of analogue signals, and so on. The project can work in two modes:

- **Manual** mode, where only specific commands can be given to some of the machines
- **Automatic** mode, where the production process is automatically managed by the PLC.
One of the major tasks to be efficiently implemented is the correct management of timing. The chosen solution was to use only one timer variable for all SFC-type programs that is started when automatic mode is chosen. In all SFC programs that need timing comparisons, the solution adopted was to read this global timer as necessary and make the desired calculations of time passed. Other tested solution, using special timing functions, like timer on (off) delay did not give expected results in SFC programs, but performed well in LD diagrams. When the automatic mode ends, the global timer is stopped and reset in order to avoid the situation in which the timer could reach its maximum and overflow. The timer is not needed in the manual mode.

Another special request was to minimize as much as possible the production time, in order to increase productivity. The solution chosen to achieve this goal was to extract the cereals immediately after weighing machine 1 is unloaded into the transporting system. In this way no time is lost, while the milling machine is prepared to receive material, the weighing machine 1 is emptied without any delay. In Fig. 64.4 an example is shown of how the timer-off delay function block is used in a LD program.

Because the impulse duration of variable b_SEL1_op (starts a motor rotating clockwise) is too short, it was extended by 500 ms. In the second line of the diagram you can see that the command is reset when:

- 500 ms has passed or the confirmation from the motor’s contactor arrived.
- The motor reached the corresponding limit.
- Confirmation from the counterclockwise contactor is not active (failure situation).

In this way the operator must only start the movement of a motor and the controller automatically stops it when one of the conditions is fulfilled.

Another job to be correctly managed was the emergency status. Because of the nature of the installations of the factory, there are frequent situations when the product process must be immediately interrupted (extractor clogging, transporters stuck, and so on).

When an emergency occurs (that could not be detected automatically) the operator must stop all the processes immediately by simply clicking a button, implemented in the user interface. Inside the programs, almost all the steps verify the status of the emergency button and the status of several sensors. When an emergency is detected, all SFC programs stop in their current step. Depending on the gravity of the situation, the operator has the possibility to resume the process from the point where it was stopped or to reset all the programs (Fig. 64.5).

Once can see that step 2 has four conditions of transition. The first is the normal behavior of the process, conditions 2 and 3 appear when some material is missing in the bin, and the fourth is true when the operator presses the emergency button on the interface screen. The latter three transitions lead the program to an emergency step 14, from where the graph can evolve to step 2 (resuming the program) or the Init step, sending the program back to its initial status.
64.8 Communication

Usually PLCs communicate with a PC by means of a serial port (RS232 or RS485) or an Ethernet interface (usually available only in more expensive and newer PLCs). Various protocols are implemented in the PLC in order to communicate (such as Profinet, transmission control protocol (TCP)/internet protocol (IP) and others). Sometimes the programmer must develop his own communication protocol if none is implemented in the PLC.

ThinkIO controllers have already installed an OPC server that can be used to exchange data between the PLC and other computers connected in the same network. This is a very useful feature because several PCs can communicate with the controller and can be used to monitor all the production process, to configure the recipe, and even to send commands to the installations (if the program allows this).

At this time one PC program was developed, with the following behavior:

- The operator can edit, save, load recipes, and send them to the PLC on the network, acting as an OPC client.
- Reports are printed at the printer after each charge finishes.

64.9 Graphical User Interface on the PLC

In a Codesys development program the user can create as many visual interfaces as needed and run this interfaces directly from the ThinkIO PLC. Practically a PC is not needed anymore to supervise the control process.

For this project five visual screens were developed, each representing a specific area of the factory, for example Fig. 64.6 shows the main area of the factory, with its complicated transport system (formed by conveyors...
and elevators), storage bins for raw material and final product, and other machines. Buttons on the screen can be clicked with the mouse and will start/stop some motors. The color of the objects usually indicates its status (started, stopped, full, empty, and so on), according to the values of associated sensors.

In this screen the operator can see information from all the sensors in the area, even the values from the weighing machines. Also the operator can manually command the execution elements from this area, e.g., can start automatic production or stop it by pressing the emergency button.

### 64.10 Automatic Feeding of Chicken

All this fodder production obtained in the feed plant is destined for feeding growing chicken in special farms. Chicken growth requires two separate processes: the supply of food and water to them and control of the environment. The chickens are prepared for sacrifice after 40 days, which is the optimum period for the chickens to be large enough and have tender meat. The control system of the factory must be very efficient in order to minimize the cost per kilo of meat. Two factors influence correct growth of chickens: food quality and environmental parameters (temperature and humidity).

It is very important that the chicken do not waste energy adapting to the environment, so temperature and humidity control must be very accurate. Environment control strategy is different from summer to winter.

The process of supplying food and drink is not very complicated. There are sensors that check if there is food in the plate; when the plate is empty the control system starts the motors of the conveying system and stops them after a specific period of time. There is also an alarm system when the tank reaches a lower limit (Fig. 64.7).

### 64.11 Environment Control in the Chicken Plant

Environment control has to be the most accurate. Temperature and humidity must continually be maintained inside a specific range of values that differs from one day to another. To fulfil this, gas burners and fans are used to ventilate the interior with fresh air. To achieve a good distribution of temperature many small burners are used instead of fewer larger ones. Because the outside temperature differs between day and night, not all capacity of the fans is needed all the time. To adjust this, variable-frequency drive (VFD) speed control is used. A special situation occurs on cold days when, even with no fan speed, the air flow is too strong to maintain the temperature. There are three blowers and normally all of them have to work for a good dispersion of fresh air. Anyway there is the possibility to manually select the operation of each blower. Another option is to use dumpers in each fan to control the opening of the windows. The inside temperature is controlled by a proportional–integral–differential (PID) software algorithm combined with control of the dumpers when needed. This is a continuous process and above it there is a batch process that provides the set point for temperature controller according to a temperature diagram. Usually this system is sufficient also to keep O₂ within prescribed limits, but it is not sufficient for humidity all of the time. The behavior of the indoors environment is for increasing humidity, so controlled opening of windows succeeds in maintaining the desired conditions.

Here the processes are minor, but the combination of a continuous process with a batch one does not result in a simple system. The performance of controlling these parameters combined with the provision of appropriate food for each stage makes the difference between companies. Another important influence on system performance is the positioning of temperature sensors, which should be uniformly distributed throughout the area.
64.12 Results and Conclusions

There were two important requirements to be accomplished by this automation system:

1. The ratio between different components contained in a final product had to be very close to the programmed values (maximum 5% error).
2. The quantity of final product must also be close to the programmed total quantity (2–3% error was requested).

After several weeks of system testing the results were as follows:

- Condition 1 was fulfilled, and the error was very small (2%).
- Final quantity was about 5% more than the desired quantity, because of estimated extraction, small losses in transporting system, and so on.

The solution adopted was to slightly reduce the scales for calculating the weight values for the weighing machines until the resulted quantity was within approximately 2% of the desired value. At that time the automation could be declared finished, with very good results.

We believe that the solution chosen for this automated system is very modern and has several advantages over what one might call classical solutions using other PLC models [64.2]:

- Process control and supervision do not require a PC, as all programs and visual interfaces run on the PLC.
- Fast and reliable network communication with PCs, by OPC server, in contrast to the widely used serial RS232 or RS485 communication in other controllers.
- The short working cycle due to fast processor.
- The extremely large number of I/O modules that can be managed (hundreds of digital signals monitored) by a single controller.

Future work will be to design a supervising user interface program that can access the controller directly from internet [64.3], so, e.g., the owner of the factory can be informed about production flow even when far from the factory.

64.13 Further Reading


References

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