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Food Process Control and Automation

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Abstract- Rapid advancements in computer technology, as well as rising customer and regulatory expectations for greater food quality and safety, have led the food sector to consider automating the majority of its manufacturing processes. Despite the fact that the food sector faces various specific hurdles when it comes to automating processes, the business has thrived in implementing several automated procedures. The next big step will be to integrate these "islets of automation" into a universal plant automation system, which will cover everything from receiving raw materials to delivering finished goods. Computer vision, expert systems, computer integrated manufacturing, flexible manufacturing systems, systems engineering, and other novel technological tools have enabled the integration of a large number of batch operations into a single manufacturing system design, allowing for on-line and uninterrupted control.

Keywords: Process control, automation, manufacturing, food industry, sensors.

I. INTRODUCTION

Manufacturing plant automation has received a lot of attention in recent years, and it will continue to do so in the coming years, perhaps even more vigorously.

The tremendous expansion in computer hardware and software technology is largely to blame for the growing fervor in industrial automation. Because computers have infiltrated practically every part of our lives, the general public has come to anticipate a high level of automation in all aspects of the production process. Process control is a critical enabler for designing and implementing long-term solutions in the process and energy industries [Daoutidis et al., 2016].

Sustainability is becoming a pervasive trend, a guiding and organizing principle that is expected to define societal and economic development in this century, driven in part by concerns about climate change and its connection to fossil fuel use, as well as the growing realization of the common threads connecting food, water, and energy across ever-expanding boundaries. It is also becoming a major driver of technological innovation at the same time. Renewable energy and green engineering are examples of terms used in this context [Garca-Serna et al., 2007], green manufacturing [Paul et al., 2014], green chemistry [Anastas, 2009], green design, green products, and industrial ecology [Bakshi et al., 2015] replicate main scientific and technological pursuits, underwritten by sustainability considerations.

The pursuit of energy efficiency, waste minimization, the utilization of renewable raw materials and energy sources, and the assessment/tracking of material and energy flows beyond enlarged boundaries are at the centre of their efforts.

II. CHECKLIST FOR AUTOMATION IN THE FOOD INDUSTRY

A successful automation strategy hinges on:

1. Defining a vision of the company and its operations
2. Developing other automation scenarios
3. Defining criteria to assess each scenario such as:

- Need for production flexibility
- Need for system expansion to meet increasing automation requirements for open architecture

- Easiness of operator and engineer interaction with the system
- Availability of assistance from vendor
- Range of advanced, proven technologies offered by vendor

4. Conducting a life-cycle cost study of challenging alternatives
5. Creating a well-coordinated implementation strategy [Dahm and Mathur, 1990]

III. PROCESS CONTROL

In the food processing industry, process control has become an essential component.

The primary motivation for implementing process control is to improve the process's economics by attaining, among other things, the following goals:

1. Reduce product quality variance, establish more consistent production, and increase yield
2. Ensure the safety of the process and the product
3. Improving operator productivity by reducing the number of people on the job.
4. Reducing waste and
5. Optimizing energy efficiency [McFarlane, 1995 and Pyle and Zaror, 1997].

Processes are either operated in a steady state, where the process conditions do not change, or in an unstable state, where the process conditions change over time. In most real-life scenarios, the latter occurs, necessitating control action in order to keep the product inside parameters.

Although there are many various sorts of control actions and reasons for managing a process, any control action must have the following two steps:

- Measurement of process parameters with precision.
- Control systems are used to manipulate one or more process parameters in order to change or rectify the process behavior.

It's important to remember that a well-designed process should be simple to manage. More importantly, rather than attempting to design a control system after the process plant has been established, it is essential to examine the controllability of a process from the beginning [McFarlane, 1995].

IV. MEASUREMENT OF PROCESS PARAMETERS

As previously stated, precise measurement of process parameters is essential for controlling any process.

Temperature, pressure, mass, material level in containers, flow rate, density, viscosity, moisture, fat content, protein content, pH, size, colour, turbidity, and other essential processing characteristics are all measured using three types of sensors [Stanbury et al., 1995]

1. Penetrating Sensors:
These sensors are able to penetrate the processing equipment and make touch with the material being processed

2. Sampling Sensors:
These sensors work with samples that are withdrawn from the processing equipment on a regular basis.

3. Non-Penetrating Sensors:
These sensors do not penetrate the processing equipment and do not come into touch with the materials being processed as a result. Sensors can also be classified according to how they are used to control processes [Stanbury et al, 1995]:

4. Inline Sensors:
These are an important part of the processing equipment, and the values they measure are directly used to manage the process.

Online Sensors:
These are also an important part of the processing equipment, but the measured values may only be used for process control once they have been entered into the control system by an operator.

Offline Sensors:
The measured values cannot be used directly for process control because these sensors are not part of the processing equipment. To accomplish process control, an operator must measure the variable and enter the data into a control system. Before employing a sensor for measurement or control, the following essential qualities must be examined, regardless of the type of sensor chosen:

- Response time, gain, sensitivity, ease and speed of calibration,
- Accuracy, stability and reliability,
- Material of construction and robustness and
- Availability, purchase cost and ease of maintenance.

References can provide detailed information about sensors, instrumentation, and automation control for the food business [Kress-Rogers and Brimelow (2001) and Moreira (2001)].

V. CONTROL SYSTEMS

Control systems could be of two types: manual and automatic controls.

1. Manual Control:
In manual control, an operator reads the process parameter that has to be regulated on a regular basis and, if its value deviates from the set value, initiates the control action required to return the parameter to the set value. The ability of individual operators to determine when and how much modification to make is critical to the effectiveness of manual control operations.

As a result, manual control can be employed in situations where changes in the manipulated parameter cause the process to alter slowly and insignificantly. This is viable in plants with few processing steps and small process upsets, as long as the operator has enough time to fix the process parameter before it exceeds acceptable tolerance.

Otherwise, in terms of labour, product discrepancies, and product loss, this strategy could be quite costly.

2. Automatic Control:
Control loops can be used to control process parameters measured by numerous sensors and instruments in automatic control.

Three basic components make up a typical control loop [Stanbury et al., 1995]:

2.1 Sensor: The sensor detects or measures process parameters and outputs a measurement signal that the controller can understand.

2.2 Controller: To compensate for any differences between the two signals, the controller compares the measurement signal to the set value and generates a control signal.

2.3 Final Control Element: The final control element receives the controller's control signal and adjusts or changes the process by bringing the measured process property back to the set point, such as controlling liquid flow by altering valve settings or pump speed.

An automatic control system could be classified into four main types:

- On/off (two position) controller
- Proportional controller (p-controller)
- Proportional integral controller (pi controller)
- Proportional integral derivative controller (pid controller).

VI. PROCESS CONTROL IN MODERN FOOD PROCESSING

Control applications in food processing, as per McFarlane (1995), is discussed in the perspective of three categories of products:

- Bulk commodity processing, e.g. Grain milling, milk, edible oil, sugar and starch production, where control is most advanced,
- Manufactured products, e.g. Pasta, cheese, in-container and aseptically processed products, and
- Products that are subjected to processing methods essentially designed to retain their original structure, e.g. Meat, fish, fruits and vegetables.

Regardless of the products, food processing process control has progressed from attempting to control specific variables such as level, temperature, flow, and so on to systems that ensure smooth plant operation with timely alarm signaling.

The systems are also designed to provide critical data from the shop floor up to vertically structured systems such as supervisory control and data acquisition (SCADA), manufacturing execution systems (MES), and interfacing with complex enterprise resource planning systems (ERP) that may be connected across multiple manufacturing sites.

1. Programmable Logic Controller:
In modern control, the programmable logic controller (PLC) is the most popular option. It's a microprocessor-based system that uses data linkages to communicate with other process control components. Ladder logic, which was originally created for electrical controls utilizing relay switches,

is extensively used in PLCs. Programs can be written in a number of different languages. The keyboard can be locked or removed entirely once the programme sequence has been entered into the PLC for security reasons. A PLC controls a process by using sensor inputs to make choices and updating outputs to drive actuators.

Thus, a control loop is a continuous cycle of the PLC reading inputs, solving the ladder logic and then changing the outputs. A real process will inevitably change over time and the actuators will drive the system to new states (or modes of operation). This implies that the control performance relies on the sensors available and its performance is limited by their accuracy.

As a result, a control loop is a continuous cycle in which the PLC reads inputs, solves ladder logic, and changes outputs. Over time, a real process will alter, and the actuators will push the system to new states (or modes of operation). This means that the control system's performance is dependent on the sensors available and is limited by their precision.

VII. TYPES OF CONTROL SYSTEMS

The various ways in which PLCs and larger computers might be brought together in an integrated control system can be classified into three groups:

- Dedicated systems
- Centralized systems
- Distributed systems

These are described in detail by Teixeira and Shoemaker (1989).

1. Dedicated Control Systems:
Local equipment controllers (PLCs) are fundamental parts of the process plant that are dedicated to controlling a single unit operation. Controlling the temperature of a heat exchanger or combining several materials into a prepared batch are two examples.

They don't send data to other computers; instead, they receive on/off commands from a central control panel. They are simple computers with the ability to accept data from sensors and transmit signals to actuators. They may also have data logging, report generating, and automatic set-point adjustment capabilities. They've remained popular because they're simple to integrate into existing processes without requiring major changes to the control system, as well as being simple to use and inexpensive. However, they are often built for a specific use, and changing the pre-programmed operating sequence is challenging.

2. Centralized Control Systems:
In these systems, a mainframe computer or big mini-computer in a centralized control room monitors and operates several on-line controllers, which then regulate the process in designated zones. To keep operators informed about the state of the process, each on-line controller may have a printer, data logger, and visual display.

They can be quickly reprogrammed to adapt process changes, and they can also generate reports and communicate with other computers. An example is presented by Anon (1987), who describes completely automated milk processing factory in which each piece of equipment is automatically controlled to maintain pre-set temperatures, pressures, and flow rates. Each process area has a mimic panel that displays the status of the process variables on a constant basis.

Closed-circuit television cameras monitor the plant and send data to displays in the central control centre. At a rate of 998 inputs every 7 seconds, the central computer examines the positions of valves, fluid levels, pressures, flow rates, densities, and temperatures in the processing equipment.

When a failure occurs, the computer sounds an alert and prints a printout of the faulty equipment, its position, and the type of the fault for the operators in the control room. At any time, the computer prints full production data and stock status. Larger systems can monitor 5000 inputs and manage 200 plant actuators at a rate of 2000 per second.

Despite the fact that centralized computer control systems have been used in large companies for several years, their main disadvantage is that any failure in the central computer could result in the entire plant being shut down unless a costly standby computer with equivalent capacity is available to take over.
As a result, distributed control systems that do not suffer from this drawback are becoming more popular.

3. Distributed Control Systems (DCS):
These are a type of integrated control system in which each section of a process is managed separately by a PLC, and the PLCs are both linked together (process interlocking) and connected to a central computer via a communications network [Lasslett, 1988]. To save money on wiring, each PLC controller is near to the equipment it regulates, and each has an operator's station with a graphical display and control inputs.

Although distributed control systems have higher capital and programming expenses than other systems, they are more flexible in terms of changing processing conditions and do not have the risk of whole plant shutdown if one component fails [Persson, 1987; Dahm and Mathur, 1990].

VIII. SUPERVISORY CONTROL AND DATA ACQUISITION

The supervisory control and data acquisition (SCADA) system is not a comprehensive control system, but rather a software package that sits on top of hardware, usually via PLCs or other hardware modules, at a supervisory level [Daneels and Salter, 1999].

SCADA systems are made to work with a variety of operating systems. In a SCADA system, there are two main layers: (1) the client layer, which serves as the human-machine interface, and (2) the data server layer, which communicates with devices such as PLCs and other data servers to handle process data and control activities. Such communication may be established by using common computing networks. Common computing networks can be used to establish such communication.

Modern data servers and client stations are frequently based on the Windows NT or Linux operating systems. Scalability is also possible with SCADA-based control systems by adding more process variables, specialized servers, such as for alert handling, or more clients. This is usually accomplished by connecting multiple data servers to multiple controllers. Each data server has its own configuration database and real-time database (RTDB), and is in charge of a certain aspect of the process, such as data collecting, alarm management, or archiving. Reports can also be prepared manually or automatically, then printed and archived. SCADA systems are generally dependable and resilient, and the vendor typically provides technical support and maintenance.

IX. MANUFACTURING EXECUTION SYSTEMS

Manufacturing execution systems (MES), as defined by Fraser (2003), are software packages that have been used in process industries for a number of years to support essential operations and management functions such as data collecting, maintenance management, quality control, and performance analysis. However, it is only in the last several years that a serious effort has been made to integrate factory floor data with enterprise resource planning tools (ERP).

Modern MES incorporate supply chain management, mix it with data from the factory floor, and offer real-time results to plant managers, thereby integrating supply chain and production systems with the rest of the business. This provides a comprehensive view of the company, which is required to support a "make to order" model. MES can track material usage and status information as well as handle production orders. The software gathers data and contextualizes it, allowing it to be utilized for real-time decision making and performance monitoring, as well as historical analysis. Although the system merges monitoring and control into a unified idea, its architecture is fundamentally open and modular, allowing for the operational flexibility required.

Operator control is the interface between the plant operator and the process control modules, allowing activities like routing and storage tank selection to be initiated with a single mouse click. It is feasible to combine a graphical depiction of plant and other written information using a range of software tools.

An operator can rapidly get more detail on any particular section of the plant by using the zoom feature. This functionality can be used to teach new operators how to operate the system. This part also stores process data, which can be retrieved quickly, for example via ‘pop up' control windows. The process control model includes data on the process and the parameters that must be regulated. It may also contain flow routing and control, storage information, and cleaning cycle sequences. These

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modules have the capacity to control things in real time. Information about the recipe, ingredients, and product specs may be found in the batch and recipe section.

This guarantees that the appropriate proportions of ingredients are used and that the product quality remains consistent. All key parameters can be monitored in real-time graphs, displayed on the screen, and logged for reports. The production data modules serve as a logbook of each processing unit's activities, detailing the product's origin, treatment, and eventual destination.

The logbook can also be used to evaluate processes and ensure traceability. The service and maintenance modules keep track of things like equipment run times, valve stroke counts, and equipment alarm limits, among other things, so they can spot malfunctioning or worn units before they break down. This makes it possible to develop a preventative maintenance programme. Finally, the input and output modules handle the real connections between process control and monitoring and physical elements (such as valves, pumps, and so on) in order to provide a comprehensive and detailed inventory.

X. CONCLUSION

The majority of food firms are currently experiencing capital budget restrictions. There is an unquenchable desire to enhance efficiency and find significant incremental improvements in manufacturing. One strategy to release hidden potential in existing processing facilities is to properly integrate process control.

Savings that can be made by various sectors of the food and beverage industry by enacting appropriate control of the manufacturing process are detailed in the United Nations Environment Programme's (UNEP) energy efficiency guide (http://wedocs.unep.org), which aims to provide companies with unrestricted, self-determining, and trustworthy guidance on many aspects of efficient energy use.

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