AUTOMATION AND CONTROL IN FOOD PRODUCTION

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Contents

Summary

Adequate automation of food production strongly depends on the process design. The present chapter deals with highly automated food processes. It primarily elucidates some aspects of food automation on the technically oriented levels and is focused on characteristics of processes as well as on related actuators, sensors and controllers.

The most remarkable difference from other technical fields is the presence of substances of biological origin in food production. In general, these substances are not only sensitive to mechanical, thermal and chemical stress factors, but also have a structure, which consists of several phases and components. Furthermore, food processing is often accompanied by microbiological and biochemical reactions. In some cases automation must avoid any damage of cell cultures; in many other cases it must ensure their

inactivation to guarantee food safety and shelf life.

It is well known that the food production processes are strongly non-linear, time invariant and often unstable. Automation of food production has to handle these properties properly and also to employ them actively. This is, for example, necessary for generating the desired food structures, for inactivating microorganisms and for avoiding certain biochemical reactions which can lead to a substantial decrease in food quality.

As a consequence of the particular properties of biotic and abiotic systems involved in food production neither specific actuators nor adequate sensors are available in general. Furthermore, due to missing of suitable online sensors, most of the production processes must be performed by using an open loop control.
Strategies for modeling, diagnosis, prognosis and optimization of food production processes strongly depend on the available knowledge base. Missing sensors lead to gaps in the knowledge base which, in general, increase with the complexity of the food. In the present chapter some modeling tools are discussed which can extract knowledge from different sources. Fuzzy Logic Systems (FLS) and Artificial Neuronal Networks (ANN) are considered as highly potential tools for automation of food processes.

In the future, new developments of specific actuators and diagnostic systems are required in order to overcome the restrictions, which hinder the realization of closed loop controller for most food production processes at present. Additionally, the possibilities offered by combining automation methods, i.e. by hybrids must be exploited more frequently.

1. Introduction

The provision of the world population with food represents one of the most important future challenges for science and technology. In this context many different objectives arise. In many countries of the world, the most urgent task is to satisfy the original nutritive minimum requirements. On the other hand, food has further functions in the industrialized nations as the settlement of a special enjoyment or the promotion of health.

Thus, food is produced or processed under very different conditions. A considerable share of the population consumes products directly out of nature or out of the characteristic agriculture. In the industrialized nations people meanwhile eat up predominantly such food, which stems out of a far mechanized agriculture and are prepared in large industrial plants.

Furthermore, any discussion regarding the automation of food production must distinguish the original production and the further treatment from the goal of preparing food for consumption, preservation or refinement. For example the original production of fish and sea animals take place predominantly in the oceans, those of fruit and vegetable in agricultural production centers. As a matter of fact, the automation in food production farms or centers differs fundamentally from such automations in factories.

1.1. Scope

The present chapter focuses on the essential matter of the application of automation in food processing centers. But even if this thematic restriction is undertaken, the variety of automation tools employed appears to be too comprehensive for being presented in this chapter. Figure 1 serves as an illustration of this statement.

Figure 1 shows a strongly simplified hierarchical scheme of the automation in a food processing company.

In the company management level strategic directives have to be elaborated. This level specifically requires automation tools for storing, transforming and evaluating technical, administrative and economic information. Particularly, information coming from the other levels must be condensed adequately in order to provide a suitable information basis covering essential data, which facilitates managerial decisions.

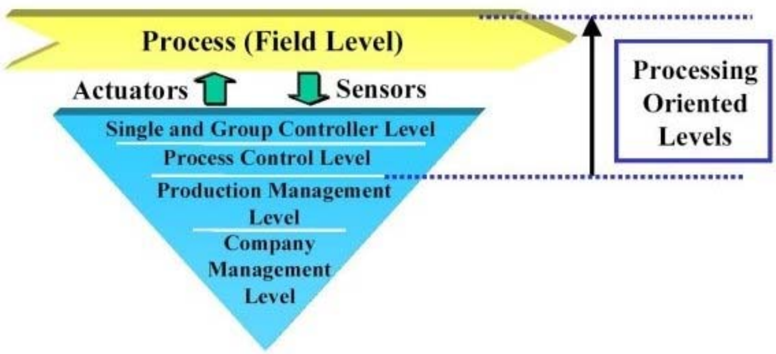

Figure 1: The (inverse) pyramid of automation (the unusual inverse representation takes into consideration the new awareness in modern business philosophy in which the work in all levels should be supported by the company management level)

In the production management level, all measures needed for preparing and monitoring production are performed. Therefore, its main task is to treat resources in such a manner that the directives elaborated in the company management level can be applied as effectively as possible. Typically, automation tools of this level of the pyramid are planning and scheduling means with strong human supervision.

Automating the company and production control level requires completely different automation systems than in the processing levels. In accordance with this, the present chapter focuses on the technically oriented levels, i.e. on the processing oriented levels, whereby especially the automation of the conversion processes of the raw materials to edible food is discussed.

The processing oriented levels can be subdivided into the process control level, the single and group controller level and the field level in which the conversion and refinement of food occur. Thus, the field level can be considered to consist of physical, (bio-) chemical and (micro-) biological systems (i.e. of components which form and act as entire units). The actions and interactions of these systems often lead to a large variety of processes and sub-processes. Most typical processes are discussed in detail below.

In the food industry substantial efforts have also been engaged for automating the packaging of food and logistical processes. In fact, these processes strongly affect the economical benefits of a company. On the other hand the automation tools used in this context are very similar to those used in other technical sectors and are not specific for food industry. Therefore, these areas are considered to exceed the scope of the present chapter.

1.2. Basic Considerations on the Automation of Food Processing

The discussion of food treatment from the process automation aspect requires first of all an unambiguous definition of what is a *process*. In this context, the biological origin of the food must be noted especially. This places a clear distinction feature in comparison to many other production areas in which predominantly inorganic or synthetic materials are manufactured.

It is well established to define a *process* as the action of systems which participate in or are subject of automation. Thus, a *process* represents all measures in which mass, energy and information are transported, transformed or stored (see Figure 2).

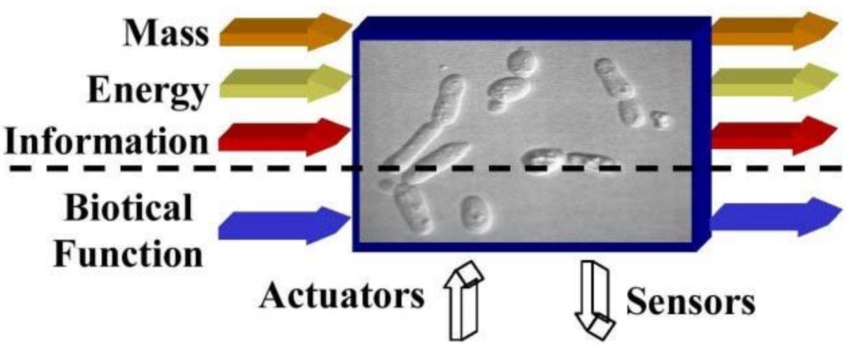

Figure 2. Illustration of the definition of a process in automation. The biotic component often available in food production processes requires an extension of the usual definition in order to take into consideration the vital function (a yeast cell suspension is depicted in the centre of the figure as a representative biotic system).

In general, sensors and actuators are assigned to the process. Therefore, they form the base of observation, visualization and diagnosis of the process. Meanwhile, the actuators possess the task of intervening into the process in order to achieve the desired result. A detailed consideration of the particular characteristics of sensors and actuators required in the automation of food production processes is given below.

Returning to the discussion of Fig. 2, a consideration of the balanced quantities appears to be useful. Mass and energy are conserved quantities. Accordingly, they can only be transported, transformed and stored in such a way that their total amount does not change. On the contrary, special measures must be encountered in the management of information to perform a desired condensation of information or to avoid undesirable information losses.

In the processing of food, biologically active (biotic) or biologically inactive (abiotic) systems are available. In this context the classic *definition of a process must be expanded* (see also Figure 2). In addition to the balance of mass, energy and information, a concept for automating food production requires also considerations regarding the non-conservative vital function of biotic substances.

In some cases the goal of the automation is to preserve this vital function. To illustrate this clearly, the living cultures in yoghurt products should be mentioned. For the final consumer, they represent an important quality feature so that each process intervention with lethal consequences for the cultures automatically forbids itself.

In other cases, automation aims at the inactivation of microbiological systems. This proves to be especially important if a threat for persons emerges from the biotic system in question.

Because food cannot be safety per se, and even a very single microbiological germ can lead to severe consequences, restrictive regulations are in vigor in order to prevent dangers. Any automation concept must transform these regulations into reliable technical procedures and systems.

The inactivation of biological components of food systems ensures a stable quality of food. For example, enzymes can release biochemical reactions in food causing aroma or color changes, so that the acceptance of the consumer becomes questionable. This provides a further example for the restrictions imposed to the automation of processes in which biotic materials are treated.

2. Automation of Food Production in the Processing Oriented Levels

The next sections deal with a more detailed description of the automation of food manufacturing processes. In this context it must be stated that in food production a large number of processes with strongly different operational characteristics is available. In the food production centers considered in this chapter the raw materials must be pre-treated in general, see Figure 3. The pre-treatment is commonly based on mechanical, thermal, enzymatic or chemical operations.

For example, softening of the “raw material water” by equilibrating its mineral content represents a typical chemical preparation step which is often required when producing beverages. Vegetables and fruits are washed, peeled, reduced to small pieces and, often, thermally pre-treated in order to meet hygienic requirements. Enzymatic pre-treatment of malt (see Figure 3) plays a dominant role for example in the beer production, especially during malting and mashing.

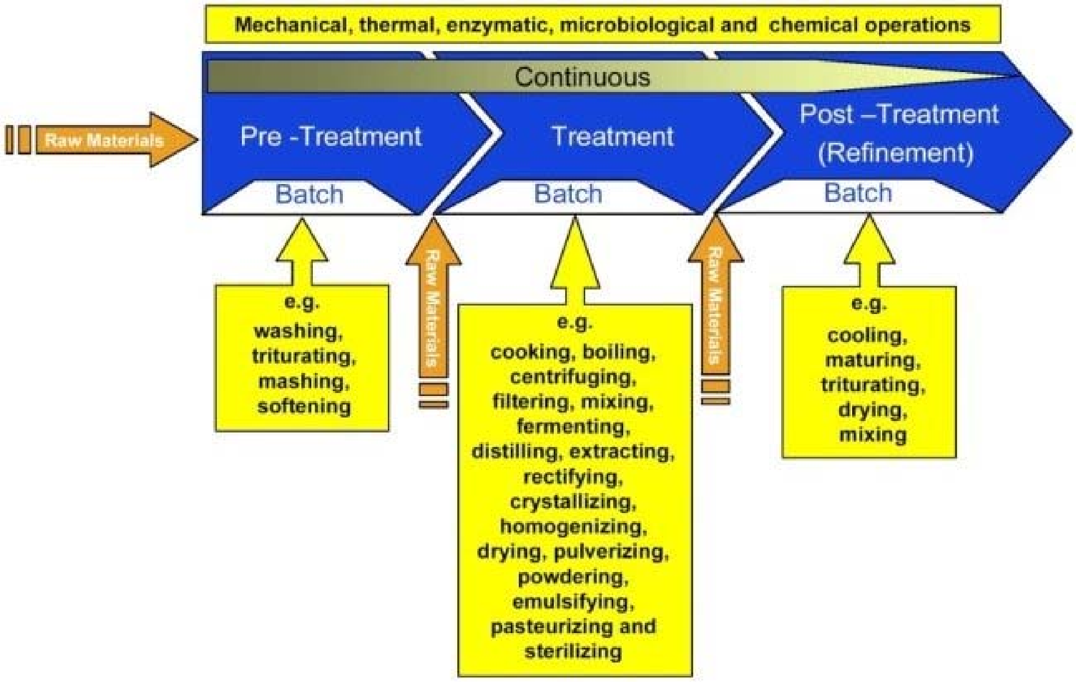

Figure 3: Schematic representation of the general treatment of food.

In the main production step totally different operations such as cooking, boiling, centrifuging, filtering, mixing, fermenting, distilling, extracting, rectifying, crystallizing, homogenizing, drying, pulverizing, emulsifying, pasteurizing and sterilizing are performed.

Typically post-treatment operations are maturing and cooling. In this context it is to be mentioned that in most of the cases batch production is performed, compare Figure 3. Continuous processes, such as used when treating UHT-milk, represent exceptional cases. Of course, this provides a further distinction criterion when compared to other productions.

In general, filling and packaging are the final production steps. Additional processes (not shown in Figure 3) related to food production are those connected to the management of energy and environment, i.e. waste water treatment.

As a typical case, Figure 4 illustrates the production of pressed cheese. Hereby, the raw material (milk) needed is delivered by animals (bovines). In contrast to this, in Figure 5 the production of Japanese soy sauce is depicted graphically.

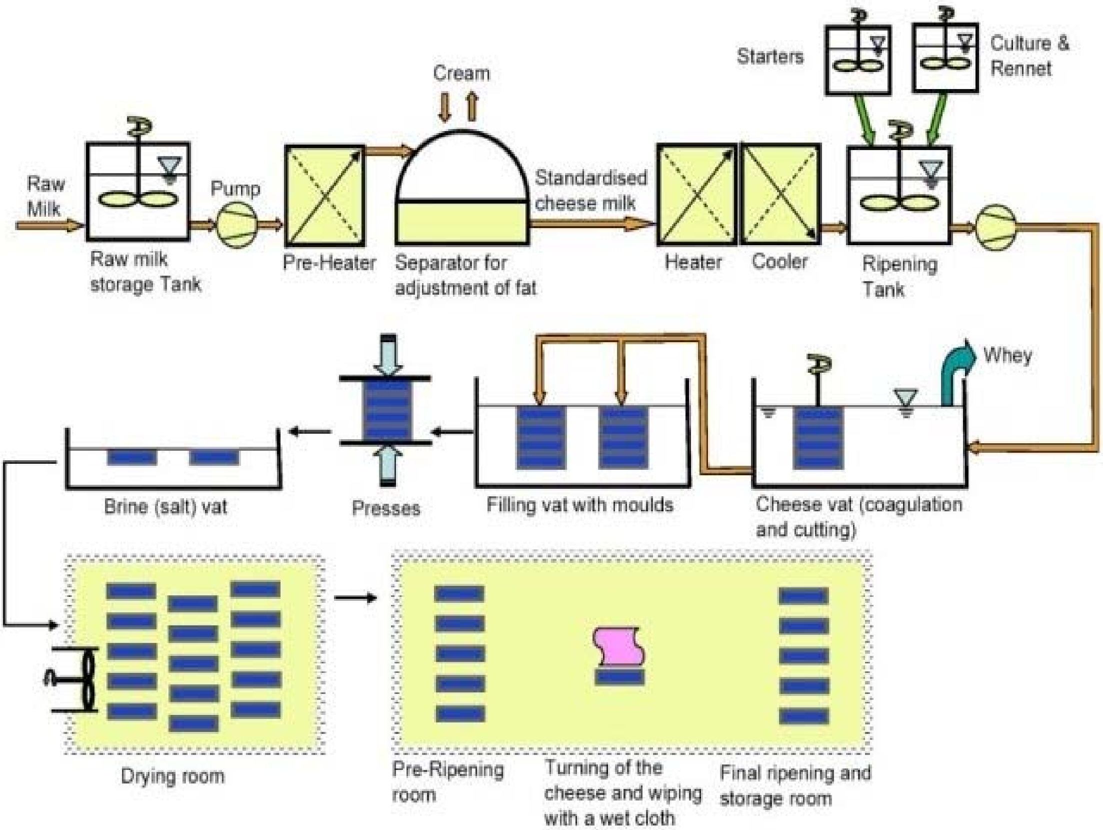

Figure 4: Flow diagram of pressed cheesed as an example of food production with raw materials from animal origin.

The complexity of food treatment in both cases is obvious. Both examples also demonstrate clearly that physical, (bio-) chemical and microbiological processes participate concurrently or separately in food production. In modern production centers most of them are automated at least partially.

But, in spite of the obvious variety of the related processes it represents a real difficulty to describe here a common automation concept valid for all processes involved. On the other hand, some of the operations general required in food processing (e.g. separating, pressing, drying and crystallizing, see also Figure 3) are somewhat similar to those in the production of other goods.

Therefore, it appears necessary to focus in the present chapter on the most typical processes for food production. Uncertainly, these are those in which biotechnological conversions occur (see also Figure 2).

For convenience, these processes are considered starting from the related systems. This allows treating them basically by the means of system theory. Since nearly all real biological processes are time-variant and highly non-linear in nature, the powerful collection of methods concerning the aspects of controllability, stability and operability of linear systems cannot be applied. Furthermore, the fundamentals of process control are discussed inclusively tools for modeling and optimizing. Last but not least, some peculiarities connected to the sensors and actuators required for this purpose are presented.

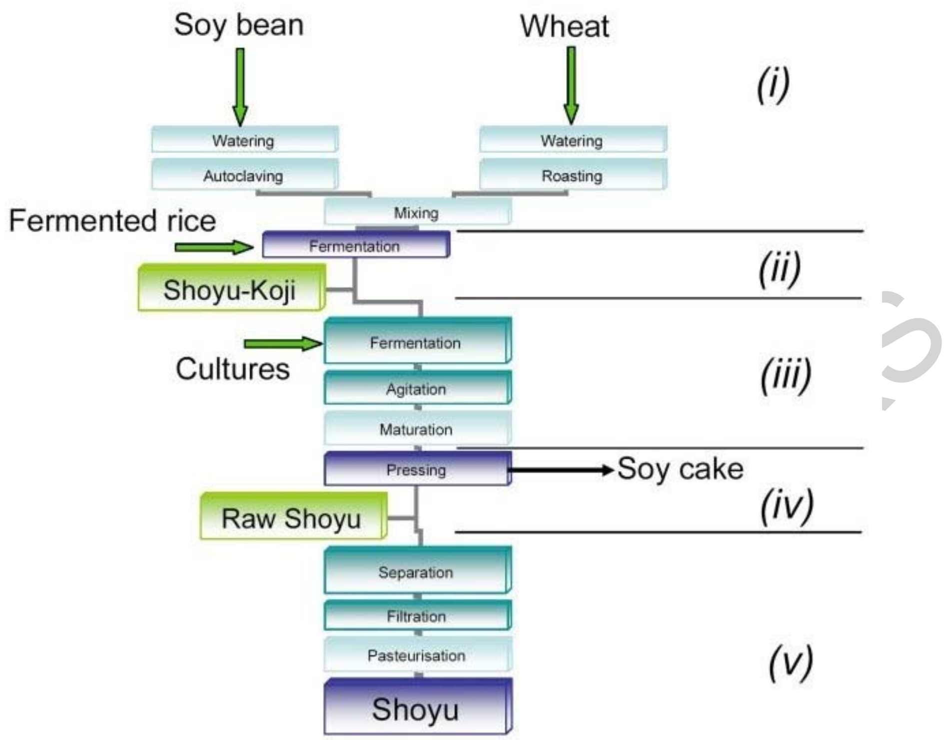

Figure 5 : Flow diagram of Japanese soy sauce as an example of food production from vegetable raw materials. The production process can be subdivided into five sub-processes: (i) raw material pre-treatment; (ii) production of koji; (iii) treatment of mash; (iv) separation processes; (v) refining.

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Biographical Sketch

A. Delgado was born in Spain in 1956. In 1969, he immigrated to Germany, where he completed his high school education. He studied energy and chemical engineering at the University of Essen, where he afterwards received his Dr.-Ing. in the field of fluid mechanics in 1986.

Subsequently, he worked as head of the Department of Fluid Mechanics and Microgravity at the Center for Applied Space Technology at the University of Bremen, where he received the Venia Legendi in 1992. After a research activity in the industry and gaining experiences as lecturer in Bremen, he became chair holder of the Chair for Fluid Dynamics and Process Automation at the Technical University of Munich in 1995.

Since then, he is deeply involved in many different scientific committees and, furthermore, acts as peer reviewer for different international leading scientific journals and panels. Up to the present, he has published more than 120 papers on different topics including flow turbulence, rheology, fluid mechanics under compensated gravity, automation of processes in food- and biotechnology, experimental techniques, numerical simulation and high pressure treatment of food.
In the present, he is head of the department for food and nutrition sciences as well as study dean of the study faculty of brewing and food technology.