Introduction to Process Control

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Introduction

Using available technology and energy resources, and applying various unit operations in a systematic, rational manner, meat processing plants should convert very differentiated and/or diversified raw materials into products possessing desired attributes, commonly accepted by the consumers in the most economical way (Figure 1). The unit operations in meat processing plants are generally run in controlled process conditions mainly: temperature, humidity pressure, flow rate, etc.; and they should be safe for operators and follow environment regulations. The process conditions should be controlled at the optimum levels for minimum operating cost, maximum profit, and desired attributes of the product.

Process Control

Technology of process control has advanced with the availability of low-cost microprocessors, programmable logic controllers, neuro-fuzzy logic, statistical process controls, and other control facilities and/or methods. The paramount role in implementation and progress of automation and process control was based in the past, and partly also at present on:

Transducers–variable-resistance or potentiometric, linear variable differential transformer, capacitative, piezoelectric, photoelectric, photoconductive, inductive displacement, and velocity.

Specific sensors–thermocouples, resistance temperature detectors, thermistors, optical pyrometry, solid state temperature sensors, and enzymatic sensors.

Strain gauges–semiconductor strain gauges, gauge factor, load cell, measurement, and temperature compensation.

Flow–rotameters, positive displacement type flow meters, vortex flow meters, hot wire anemometer, turbine meter, magnetic flow meter, ultrasonic type, Doppler),

Level–diaphragm and conductive probes, float type capacitance and ultrasonic level sensors),

Relative humidity, water activity, pH and other ions, color, composition, moisture, biosensors, special sensors etc. (Pearson and Dutson, 1994).

Nowadays, even for small and/or medium sized meat plants, a computer-based process control system is a crucial and essential tool of paramount importance to handle the process information flow with an automated system to control the processes and to ensure optimum product quality and productivity (Figure 2).

Digital or computer-based process controls optimize process and/or equipment efficiency. Computerized controls are commonly used for new facilities as well as to upgrade existing equipment. They provide many additional advantages, such as the capability to monitor and control many operations independently and concurrently. Due to progress in construction of programmable controllers and microprocessors, computer-based control of great variety of processes drastically reduced electromechanical controls such as switches, relays, and timers commonly used in the past (Mittal 1997a, Kress-Rogers, 1973, Loey van at al., 1996).

Like many other branches of the food processing plants, the meat industry is facing increasing global competition, regulation, and consumer demands. These require new technologies and practices. The need for increased automation in the food industry is due to:

1. The elimination of extremely repetitive and monotonous tasks (operations), which caused repetitive strain injury to workers,
2. Better quality control is needed because of consumer sophistication, regulatory labeling requirements, and narrow quality boundaries,
3. The elimination of off-line quality control due to the need for more rapid correction of deviations from process and quality standards/specifications, and
4. The detection of foreign and contaminant material in food (Pedersen at al., 1990).

According to Mittal (1997a) implementation of these tasks require:

a) Fairly well established *automation* in plants, which reduces the number of machines and provides savings in labor and maintenance costs. What is also

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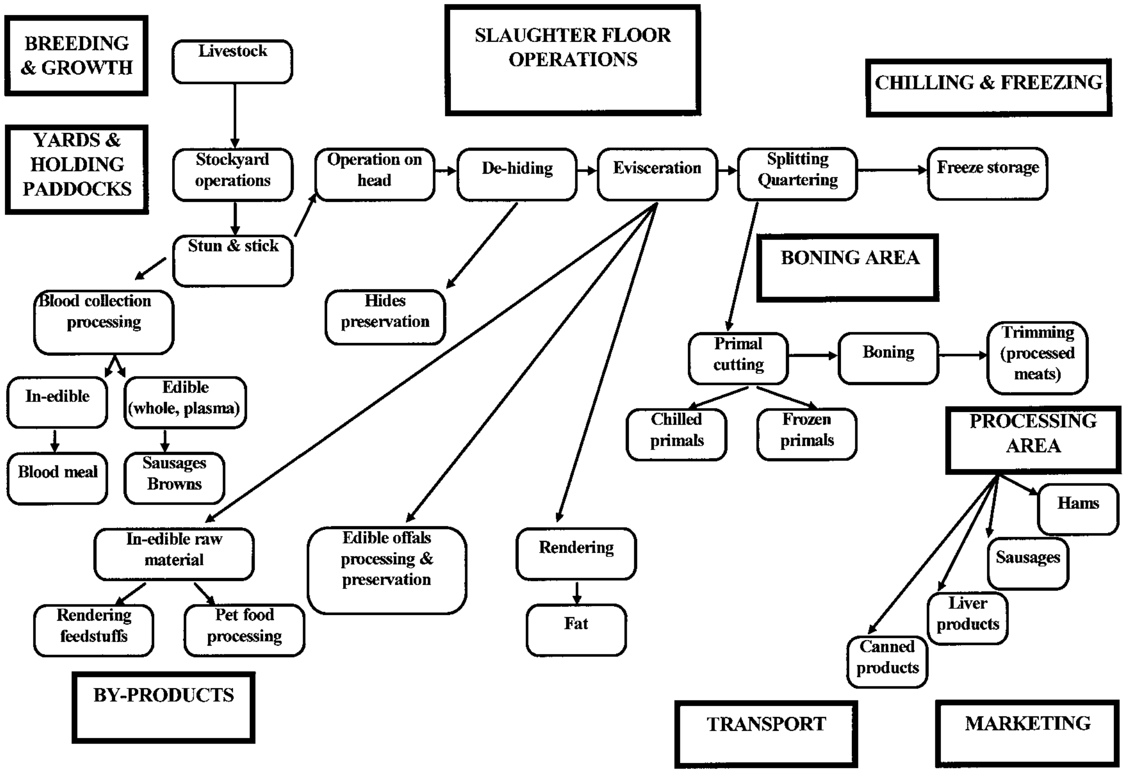
Reciprocal Meat Conference Proceedings, Volume 50, 1997.

FIGURE 1.



Schematic representation of meat industry process flow.
Source: Buhat, J.W. (1997). Modified by Duda, Z.

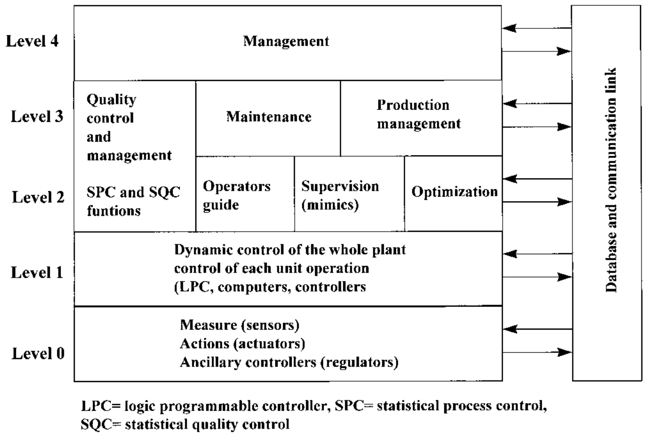
of great importance–the automated system shows none of human characteristics of fatigue, mood changes, or inconsistent judgments. It provides accurate and repeatable batches, reaching optimum operating condition faster with less adjustment. Automation creates higher efficiencies and reduces overall costs in addition to increasing productivity.

b) *Process documentation* capabilities with computer assistance is virtually unlimited, allowing the retrieval of stored information on daily, weekly, monthly, and yearly bases. Smart systems also monitor and record periodic and transient variations in product variables, which helps in further product quality improvement. The system can be used to optimize blend formulation, production scheduling, modeling of process, increasing production, safety, and efficiency in every area of the manufacturing process. Finally, the system allows implementation of total quality management (TQM) with improved process control, quality monitoring of raw material, and statistical process control.

c) Installation of computer-controlled *robots* programmed to perform many operations in animal slaughtering, carcass splitting, trimming of meat, blending sausage batters, and processing of end products. The possibility of using robots in the meat industry originated with developments in special gripping capabilities, sensors, vision, and sophisticated information management systems. This resulted in construction of modern robots which are highly sophisticated, programmable manipulators that possess mechanical arms powered by electromechanical devices, permitting multiple combination of rotation/transitional motions in 3D space and allowing performance of many operations with power, precision, and repeatability greater than human arms. For example, carcasses are nowadays commonly automatically split by robotic splitters traveling in tandem at a rate of about 1100 pork carcasses per hour (Morris, 1993; Longdell, 1996; Longdell, 1992; Wada and Khodabondehloo, 1995; Paardekooper at al., 1994; Abela and Weinberg, 1993; Khodabondehloo at al., 1995).

In the future, engineers, and/or scientists' knowledge and invention will result in new constructs, technologies, and processing solutions. A good example of the unlimited potential and fast technical progress in contemporary meat technology is the sinusoidal shape of development in beef and sheep slaughter technology. It began with horizontal slaughter operation on the floor, then switched to vertical operation on overhead rails, and now it is

FIGURE 2.



The computer integrated manufacturing (CIM) model-hierarchical approach for process control tasks.
Source: Trystam, G. and Courtois, F., adapted by Duda, Z.

TABLE 1. Sensors for the Food Industry.

	Today	
Pressure	Object recognition	Turbidity
Temperature	Colour	Mass flow
Flow	Humidity	Specific ions
level	Viscosity	Gas compositions
Position		Vibration
	Tomorrow	
	Subjective properties - smell, tastes, texture, flavour	
	Biosensors - meat freshness	
	Chemical sensors - acidity, sugar content	

Source: Dohm, M. and Mathur, A. (1990).

back to horizontal and/or semi-horizontal slaughtering, with increasing use of robots as suggested by our New Zealand and Australian colleagues. (Borggaard at al., 1996; Longdell, 1996; Pierson and Corlett, 1992).

d) Adoption of *machine vision* techniques in the meat industry for evaluation of conformation and grading of beef, pork and poultry carcasses, for the quantitative determination of visible process defects, and to examine products for foreign material, wrong color, bruises, scars, and other flaws. Several aspects concerning integral quality assurance are shown on Figure 3 (Augustini at al., 1994; Newman, 1987; Swat-land, 1995; Borggaard, at al., 1996; Paardekooper and Stekelenburg, 1991).

In the recent two to three decades, particularly now, attention of researchers representing a very broad spectrum of specializations–namely control equipment construction, computer programmers, and food technologists has been focused on process control problems. Recently in the U.S., a special research committee of the Institute of Food Technologists identified process control (as it relates to improvements in process design and operation efficiency) as a research priority. This resulted in a notable increase in the number of publications in this area, as well as many reviews and books on advanced process control techniques for the food industry (Haley and Mulvaney, 1995; Trystram and Courtois, 1994; Davidson, 1994; Perez-Correa and Zaror, 1993; Mittal, 1997).

According to the available information, there are three basic types of advanced control techniques:

1. *Model-based* controllers are formulated mathematically from a process model and specification of the controlled system performance.
2. *Fuzzy logic control* is based on heuristic process models–on rules of thumb obtained by experience and instinctive judgment–and is well suited for controlling process whose output attributes cannot be measured directly, but are inferred using other measurable information that can be obtained from the process (for example product quality in smokehouse processing).
3. *An artificial neural network* has the ability to “learn” patterns associated with particular product attributes. Process controls based upon an artificial neural network acquire knowledge of process dynamics through “training” on input-output data sets from the process that is to be controlled. It has been used as the basis for developing “smart” sensors for process control application (Table 1) (Haley and Mulvaney, 1995; Kress-Rogers, 1993; Ohashi and Karube, 1993; Kress-Rogers at al., 1993; Yano at al., 1995; Matsumo, 1995; Anon, 1994; Kauffman at al., 1990; Mittal, 1997b; Mittal, 1997c).

Newer controls, sensors, and accessories are miniaturized, more accurate, reliable, flexible, compact, portable, cost effective, easy to maintain, fast, precise, and modular. Fiber optics is used for their production. Analog sensors are replaced with digital ones improving service life and repeatability. The so called “smart” sensors already available, and those under development and testing will help provide product consistency, zero judgment error, and non-stop processing. Moreover, smart devices are made intelligent by incorporating microprocessors. A neural network-based intelligent sensor to emulate the human nose has been described (Mittal, 1997). Further development in sensor technology is needed to measure very high viscosities, moisture content, color of uneven surfaces, and thickness of material in motion. In-line, nondestructive, and real-time measurement of enzyme activity, microorganism activity, flavor/aroma, and shelf life will enhance and ensure food quality, consistency, integrity, and safety (Table 2) (Buhot, 1997).

Another quite recent approach to process control is an

TABLE 2. Principle Sensors Adopted in On-line Sensor Systems.

Enzyme sensor (electrode, column, redox)
Photospectrometer (rate of de-bleeding)
Near-infrared absorption (moisture, mould, iodine value, biogenic amines)
Fluorescence (ATP-depletion)
Ultrasonic wave echo (fat-meters)
Sound wave velocity (advancement of rigor)
Image processing (carcass classification, grading)
Gas sensor (electronic nose, exoust smoke, rendering odour)
Electrical conductivity (advancement of aging)
Dielectric constant (advancement of rigor)
Humidity sensor
Thermal flux meter (rate of heating, core temperature)
Surface thermometer (rate of freezing/chilling)
Radiation thermometer
pH (depletion of glycogen, intermediate and final compounds, advancement of aging)

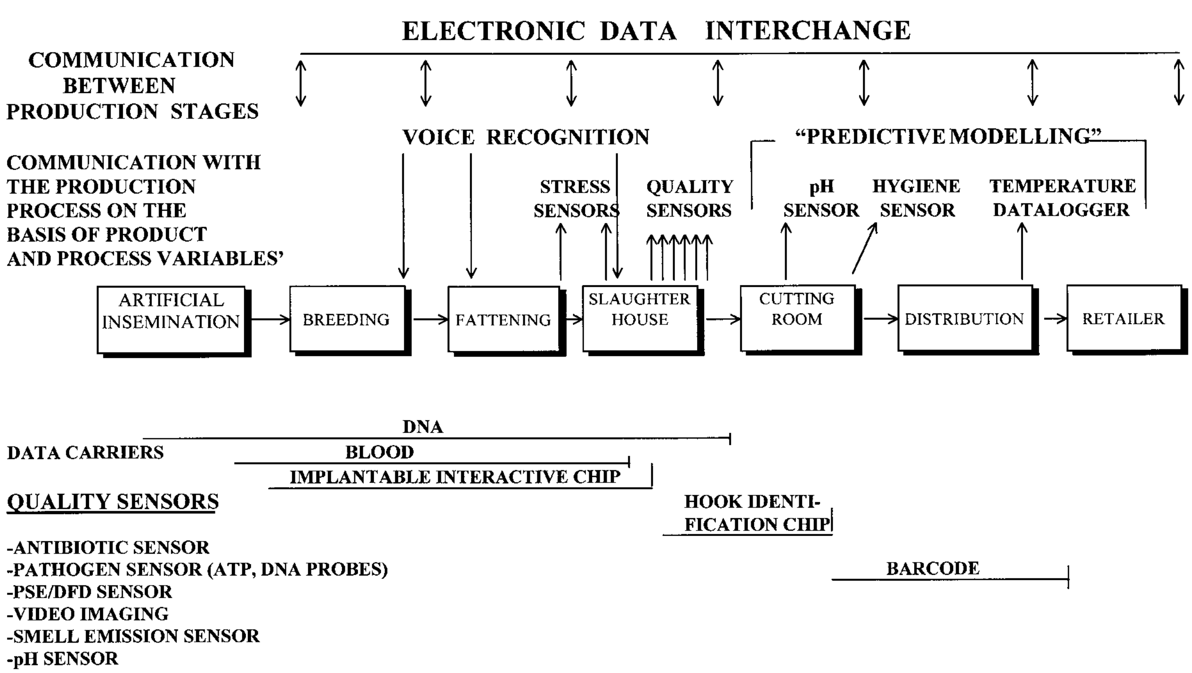
expert system defined as "an intelligent automation environment comprised of traditional and heuristic methods to solve a particular problem." This includes hardware, software, and human experts such as process design engineers, operators, and instrument technicians (Davidson, 1994). The combination of hardware and software is powerful, because it can process large volumes of data in real time, analyze patterns, recognize trends, and suggest control actions. The human component is also essential to the "intelligent control environments," because most process control problems will be better solved using human experts in a combination of methods rather than a completely heuristic approach. Thus, an expert system can combine traditional mathematical methods based on theory as well as on operating knowledge in heuristic form that can be applied when the theory does not work. But it is suggested that a decision algorithm be applied as an important first step in problem analysis in order to avoid disappointments with implementation of this still relatively new approach and technology for which low-cost, user-friendly versions of the tools only appeared recently (Figure 4).

Conclusion

In conclusion, the following should be emphasized given the brief presentation of the system. (Davidson, 1994):

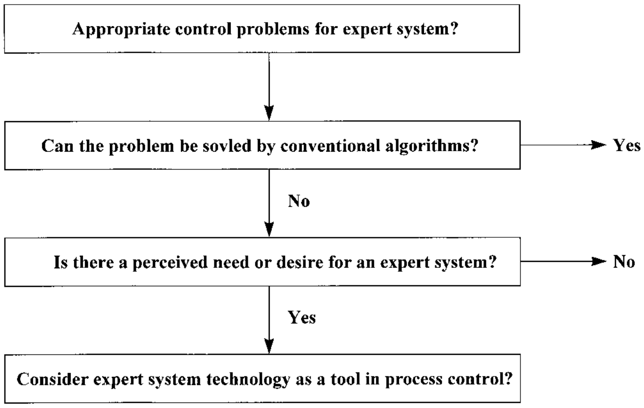
1. Expert-system technology is a useful tool for process control problems in food manufacturing.
2. Expert systems in process control are a hybrid of traditional control algorithms and heuristics.
3. Expert systems have demonstrated potential applications in the control of food processing operations. Although some uses will be specific to food systems, the obstacles that to date have prevented a wider use of computer-based control technology in the food

FIGURE 3.



Several aspects concerning integral quality assurance in pig production, pork processing and distribution.
Source: Paardekooper, E.J.D., Stekelenburg, F.K. (1991).

FIGURE 4.



Decision algorithm for expert system technology.
Source: Davidson, V.J. 1994.

industry will be overcome, and examples such as expert supervisory control will be developed.

It seems also worthwhile to stress that there is a gap between laboratory and industry in application of process control. Difficulties are related to sensors, complexity of solutions, appropriate knowledge, and the opinions of people who are not necessarily ready to take into account sophisticated technologies. Control science needs much more work in the field of steady and transient states of processes. Finally, it is necessary to emphasize that control is a multidisciplinary approach that involves cooperation between food process scientists, control scientists, engineers, and other researchers. This is an important factor for progress in both of these areas (Trystram and Courtois, 1994).

With a fairly good expectation, it can be predicted that further great impact on process control development and progress, both theoretical and practical, will result in common and strict application of the HACCP philosophy in food manufacturing and particularly in meat processing. Generally speaking, it is aimed at food safety and at good quality of end products. The HACCP system, as well as quality and safety problems, are comprehensively presented in several monographs and numerous papers (Hubbert at al., 1991; Zeleke at al., 1994; Hechelman, 1995; Tompkin, 1994; Schothorst van, 1991; Ehiri at al., 1995; Jouve, 1994; Buchanan, 1990; Dahm and Mathur, 1990; Savage, 1995; Scharner, 1997; Yano at al., 1996; Forsythe, 1996.

Selected Priority Topics for Future Research

With further development of digital electronics and computers, and particularly due to the availability of low-cost microprocessors, future research priority topics in control science related to meat technology could be predicted. With rational limitations, these research topics are as follows:

1. Firm anchorage of computerized process control in as many as possible single operations and complex processes should be envisaged and established in the near future. It should be particularly oriented toward implementation of further mechanization, automation, and robotics, beginning in slaughter operations, evisceration, grading, continuous chilling, cutting of primal cuts, trimming, products recipe (formulae) elaboration, adjustment and optimization, and implementation of thermal and smoking treatments in a programmable manner. Substantial improvement of existing systems of packaging and distribution could be achieved.
2. Much more effort and work should be oriented toward invention, construction, and implementation of widely differentiated sorts of intelligent, so called “smart” sensors and biosensors, which should be used as much as possible in the meat industry operations. They particularly should be used to control processes which are responsible for meat aging and to control the ripening of fermented meat products.
3. Further developments of the theory and practice of process control science must assure hygienic and safe food manufacturing with desired high quality of the end product, aiming at fulfilling the consumers requirements and satisfying their eating habits and demands from nutrition, dietetic, and sensory points of views. This will require us to gain more knowledge about the interaction between the process and product as well as a better understanding of the transformation of raw materials into desired end products.

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