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Implementing a Process Control Strategy for the Food Processing Industry

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ABSTRACT

This paper describes some of the current problems facing food processing companies with respect to their process control requirements. The establishment of a research project to address some of these problems is outlined. The goal of the project is to develop a generic process control/simulation platform for the food industry. Process Control/IT audits were carried out on a number of plants and from this information it was possible to identify specific requirements. Appropriate software and hardware tools have been identified and sourced. These tools provide a powerful but flexible platform from which a variety of common problems and requirements can be addressed. The necessity for the development of sensors specifically tailored towards the needs of the food industry is discussed together with ongoing work in this area.

INTRODUCTION

A recent survey carried out by the Leatherhead Food Research Association suggests that the food industry has been surprisingly slow to take up many useful technologies that have emerged in recent years (Leatherhead Food RA, 1994). The apparently healthy exterior of many food companies belies the problems inherent within them, which gives the company accountants power over engineers and process technologists (Goldsmith, 1995). The industry is now only slowly realising that investment in specific technology can result in considerable savings for relatively small capital investment. However, companies must be judicious in their choice of

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hardware and software, and thus purchase systems which are suited to their needs and not the profit margins of the process control vendors. Many companies are over-reliant on particular vendors because of their reliance on third parties to maintain, develop and update their control systems. These systems/platforms have, in general, been static in their interaction with other software packages and as a rule do not employ many of the principles of open system architecture. Thus, the International Standards Organisation (ISO) open system interconnection reference model (OSI) for information exchange between systems is rarely adhered to, or at best only partially implemented (Ferrero, 1996).

A research and development project is outlined here which is aimed at addressing the needs of the food industry as they exist today with respect to IT and process control/optimisation. The object of this project is to develop a process control toolbox based on recent developments in the software and engineering industries encompassing elements of both technology transfer from these sectors and specifically focused development. The tools and strategies developed are intended to be generic in nature and therefore to be applied across the widest possible spectrum. A centre of excellence is being established in adapting and focusing existing and developing software approaches to problem analysis and design across the broad domain of food processing both in R&D and, more particularly, in industrial applications. To these ends, a number of case studies have been selected with leading companies from the food and drinks manufacturing sector of Irish industry. The goal of these case studies is to develop specific solutions and demonstrate the technology thus developed in typical production environments. In the age of the microprocessor the food industry remains in many cases a manual one. It therefore requires a significant effort to re-educate and to update an industry that has remained, in certain aspects, technologically stagnated. The programme which now has been initiated represents the first steps along this path. It is clear that many academic institutions need to play a more interactive role with industry in improving the awareness of the technologies and tools that are available. Industry, in turn, must clearly identify its problems and address them through focused research programmes in conjunction with appropriate academic or research institutions. 'User needs specification' remains the most difficult and critical step in food process automation. It is only through interaction and discussion between the relevant partners that tangible results and progress will be achieved.

Much of the food industry is characterised by the traditional 'art' of food production and the employment of relatively few trained engineers (Skjöldebrand, 1991). At present, many of the production processes rely to a large extent on the skill and experience of the operator rather than the utilisation of a clear scientific understanding of the process. In reality the transition from 'art' to 'science' is still an objective more than a fact in many food small to medium enterprises. Clearly, any effective control system must reduce this intuitive element through the use of appropriate control feedback and sensory inputs. However, no system for the foreseeable future will be able to entirely replace the experienced operator. It certainly would be a foolish step to embark on such a course. Instead, the objective is to develop appropriate decision support mechanisms to assist both the skilled operator and supervisory personnel to effectively carry out their production/processing duties. The first step in this development aims to free the operator from many mundane tasks (simple control decisions, data logging and reporting, etc.) and facilitate concentration of time and effort on more important tasks. This is a key step in operator empowerment.

SOFTWARE TOOLS

Assuring product consistency is a primary objective of food manufacturers. A major benefit of successful automation and process control is the ability to produce a range of components in large quantities that are consistent from one batch to the next. Food products are a unique challenge, but it is clear that there is room for vast improvement given the current state of many processes. An aspect of this is the transformation of the components into a compliant or consistent form at an early stage in the process. Data processing systems which by their nature are capable of dealing with the variability and indeterminacy of food products are beginning to have an impact on food process automation. Typical of these emerging technologies are fuzzy logic systems and neural networks (Dettmer, 1994; Linko *et al.*, 1994; Martin, 1995). The essential difference between these systems and previous software tools is their ability to self-interpret the data presented to them after appropriate training of the application, i.e. they have an inbuilt 'learning' process. Some of these technologies are now filtering into commercially available packages. More interestingly from a development point of view are the number of packages available as add-on 'toolboxes' for standard programming environments such as MATLAB (Maths Works Inc.) and LabVIEW (National Instruments). These are essential in the development of any comprehensive software inventory. LabVIEW is emerging as an important tool in the process control software/development environment (see Fig. 1). National Instruments interest in this area has been further augmented with the release of their Lookout^{TM} process control software system which they claim to be the first completely object-oriented programming environment for process control applications. These packages have an open architecture and allow us to exchange data with other packages such as Excel via OLE2 (Object Linking Embedding) and DDE (dynamic data exchange) and information with databases via SQL (search and query language). LabVIEW applications also support third-party software code (e.g. C or MATLAB) via code interface nodes (CINs). This thus presents the formation of an architecture that is open, flexible and relatively inexpensive. For example, when developing a control application that requires one to communicate with PLCs from a variety of different manufacturers, it is possible to buy the necessary drivers in the form olf an add-on toolbox or user-specific drivers. The unconditional reliance on vendors can therefore be reduced at a cost that is realistic for the food industry (Kirk, 1992; Baroth & Wells, 1993; Johnson, 1994).

One of the significant changes occurring at present in the industrial software control world is the shift away from UNIX-based operating systems to Microsoft's Windows NT for small- to medium-scale process control and IT applications (Bocock, 1996; Tinham, 1996). This trend has been greatly influenced by the PC. Their ever-increasing processing power (now on a par with some workstations), low cost and the availability of a robust, secure operating system (Windows NT) has made the PC a very important element in the control and management environment. As a result, all software being developed or evaluated is compatible with the PC platform running under Windows 95 or Windows NT. This has important implications in terms of cost as it now feasible to offer low cost solutions to SMEs based on these technologies. This combination of low cost solutions with the friendly environment of the PC/Windows operating system is a useful enticement in encouraging industry to take up this new software technology initiative (see Fig. 2).

Data are becoming increasingly more available via improvements in information networking (LANs and WANs) and the increased sources of this information (MIS, LIMS, Executive Information Systems, PIMS). The challenge for the case studies in the present project is to channel this information explosion into the monitoring and management/control function. New and dynamic methods of analysing process data are being developed. By collecting data from the process to be controlled using traditional sensor technology and then fusing or combining those data, they can be analysed with the neural processing system, By inference it is then possible to monitor a specific parameter, which cannot be measured directly. The understanding or interpretation of multi-parameter information can be very powerful and allows control of a process that hitherto was impossible using traditional techniques. Neural systems work well when they are presented with a problem in the form of a

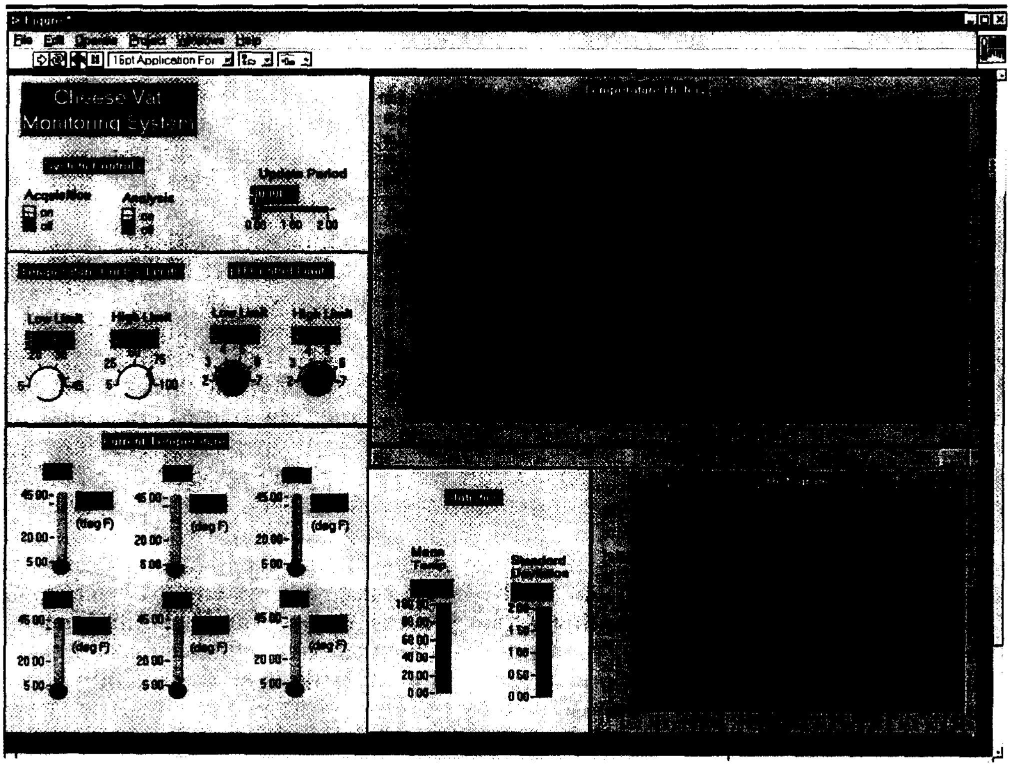

Fig. 1. The LabVIEW front panel for a proposed cheese vat monitoring system.

pattern. A neural system can be trained to recognise patterns and associate them with the correct output conditions whether digital or analogue (Skjöldebrand, 1995).

SIMULATION

One tool consistently under-utilised by the food industry is that of simulation. Simulation is the use of a mathematical model or models to describe the relationship between the parameters that can be observed in a particular system. The food industry has been neglected quite seriously in terms of simulation tools despite the significant potential of such applications. Simulation is a valuable tool for the development of a new process or the alteration of an existing one. It can be very cost-effective in comparison to carrying out full-scale trials in the plot plant. Calculations based on different conditions can be carried out rapidly on a computer yielding the results in a very short time. Full-scale experiments can thus be rationalised with considerable financial and time savings. If a production plant is to be made more efficient, with greater productivity and improved quality assurance, greater

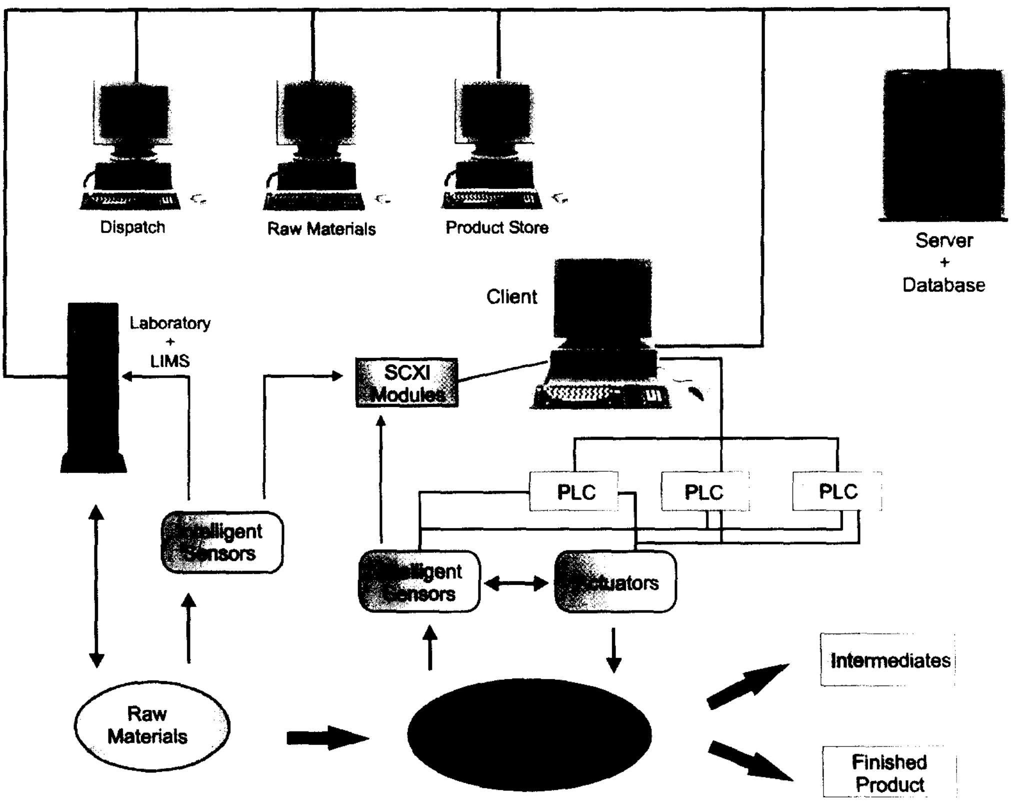

Fig. 2. A schematic diagram of a modern process control architecture incorporating many of the principles contained within the project.

knowledge of the process allied with data on the raw material and product is required. The development of model systems is also important. Increased knowledge of the physical process can save money and lead to better quality in the end-product (Skjöldebrand *et al.*, 1993).

This project has used BATCHES from Batch Process Technologies for all necessary simulation work to date. Although not written specifically for the food industry it offers a degree of adaptation which makes it useful for applications in the food industry. It has already been successfully applied to the simulation of a brewhouse operation in a Belgian brewery (Mignon & Hermia, 1992, 1994). BATCHES has the ability to simulate both batch and semicontinuous processes in the biochemical, food and pharmaceutical industries. It is a data driven package. A BATCHES simulation model consists of three buildings blocks:

- equipment
- recipe network
- sequencing information

The BATCHES model allows the user to (1) evaluate alternative system configurations and operating procedures, (2) identify bottlenecks, (3) assess the requirements for capacity expansion, and (4) evaluate scheduling strategies. The output obtained consists of graphs, and a comprehensive summary report containing a mass balance summary, equipment and resource utilisation statistics, cycle time and waiting time information and, finally, time lost due to waiting for materials and resources. BATCHES is currently being used to develop a simulation model for a local brewery.

SENSOR DEVELOPMENT

One of the main raw materials for many food products, milk, is inherently inconsistent and therefore can introduce significant variation into the properties of the final food product. Simple control of the process is proving unsatisfactory as consumer, market and regulatory demands become more stringent. Therefore, in-line quality control should become an integral part of the process control system. The increasing demands on the quality of food and food production imply a need to develop new tools and strategies to measure and control the production process. These criteria are being addressed on two levels. Firstly, a thorough process evaluation provides the basis for reliable and effective process control. Many companies are unaware of how various changes in the composition of the raw material affect the properties of the final product. The process conditions can be adjusted to compensate for the variations in the raw materials to obtain the desired chemical and physical properties. Many companies talk about the desire to reduce the variance of product specifications from the production specifications. One plant manager described their aspirations as a desire to 'narrow the curve'. Until now, the properties of the product have been specified, measured and noted, but feedback from this procedure to suit the process to the raw material in order to get the desired product has generally not been utilised (Wallins, 1995). One of the initial steps carried out in each of the case studies has been to undertake a process information audit in each plant. This information forms the basis for developing a model of the plant in some cases or identifying necessary data acquisition/sensor upgrades. Once the process is clearly understood, together with all the necessary data acquisition nodes, it is then possible to develop or adapt a monitoring, information and, ultimately, a control strategy best suited to the requirements of the plant. The second requirement is the development of necessary sensor systems. Any process control system is only as good as the data it reacts to. The most important trend in process control sensor development is the desire to move from laboratory analysis to the use of in/at-line sensor systems which can supply equivalent information. This allows more reactive response of the control system to the dynamic parameters of the raw materials and the product being produced. In consultation with the industry, a number of compositional parameters of liquid milk which are of greatest importance to the industry have been focused upon. The backbone of these sensor developments is based on the use of near-infrared (NIR) technology (Rodriguez-Otero *et al.*, 1994; Doyle, 1995). A modular approach is being adapted in the development of these sensor systems. Therefore, the electronic modules and transducer modules can be reused for different sensing requirements with only a need to develop a new 'sensing front end' for each additional application. These sensing systems will be integrated into the overall process control system (see Fig. 3).

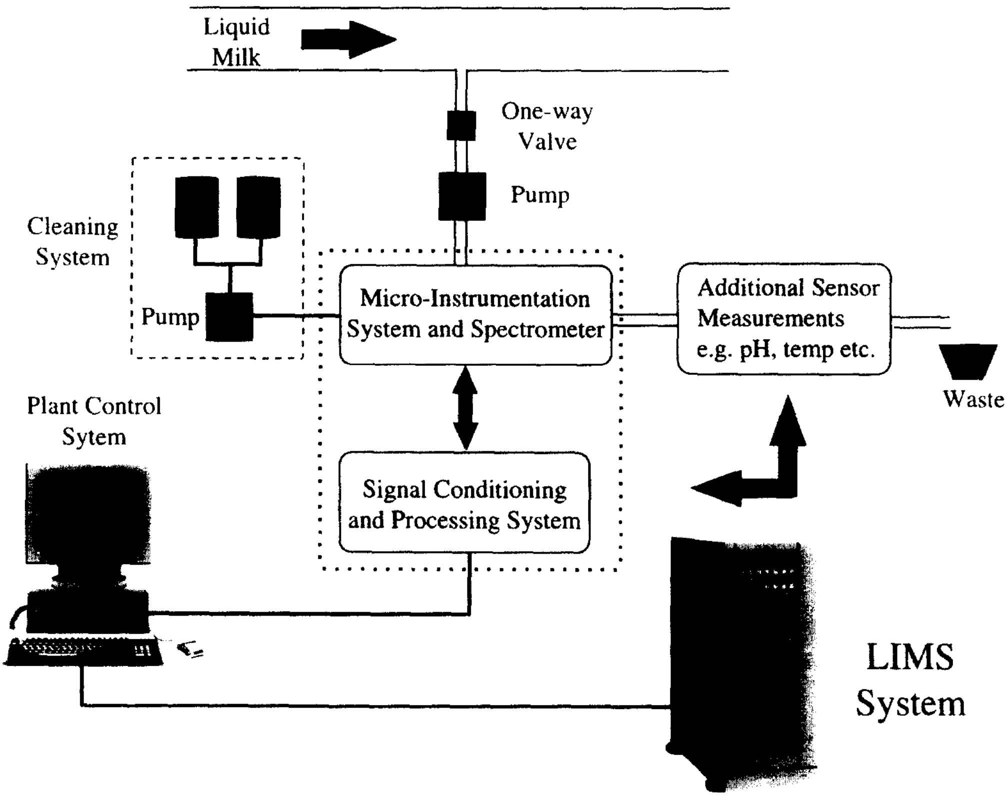

Fig. 3. Schematic diagram for a generic constitutional milk analysis system based on the use of modular micro-instrumentation units.

CONCLUSIONS

There is a clear need for low cost solutions tailored to the specific needs of the food industry. For these tools to be useful and accepted they should comply with the KISS criteria (keep it simple and stupid). The development platforms should be flexible to facilitate rapid redevelopment of tools to meet new requirements. This approach minimises both cost and development times. Significant effort must be put into educating the food industry about new technologies and their potential applications.

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REFERENCES

Baroth E. & Wells, G. (1993). Telemetry Monitoring and Display Using Lab VIEW. Paper presented at the National Instruments Users Symposium, Austin, Texas.

Bocock, C. (1996). Software straddles the drive/monitor divide. *Drives and Control*, Jan, 24.

Dettmer, R. (1994). Fuzzy control, engineering for empiricists. *IEE Review*, Jan, 17–20.

Doyle, W. M. (1995). Near-IR and mid-IR process analysis—a critical comparison. In *Advances in Instrumentation and Control*, Vol. 50, Part 1 pp. 433–441, ISA/95 The Society for Measurement and Control, New Orleans Convention Centre, Louisiana.

Ferrero, A. (1996). *The Evolving Ethernet*, Addison-Wesley, Essex, UK.

Goldsmith, P. (1995). Tasteful art of competing. *Processing Engineering*, Aug, 27–28.

Johnson, G. W. (1994). *LabVIEW Graphical Programming—Practical Applications in Instrumentation and Control*. McGraw-Hill, New York.

Kirk, J. R. (1992). A PID controller written in Lab VIEW. *Computers in Education Journal*, **2**, (2), 16–21.

Leatherhead Food RA (1994). Competitiveness in the food industry. Study for the Ministry of Agriculture, Food and Fisheries.

Linko, S., Zhu, Y. H., Eerikäinen, T., Siimes, T. & Linko, P. (1994). Artificial intelligence in bioprocess modelling, estimation and control. Proceedings of the ACoFoP III Symposium in Automatic Control of Food and Biological Processes, Paris, France. Vol. pp. 143–158. Elsevier, Amsterdam.

Martin, G. (1995). Neural network applications for prediction, control and optimisation. In *Advances in Instrumentation and Control*, Vol. 50, Part 1, pp. 433–441. ISA/95 The Society for Measurement and Control, New Orleans Convention Centre, Louisiana.

Mignon, D. & Hermia, J. (1994) Energy integration of brewery operations, *Automatic Control of Food and Biological Processes*, 401–408.

Mignon, D. & Hermia, J. (1992). Using BATCHES for modelling and optimising the brewhouse of an industrial brewery. *Comp. Chem. Eng. Suppl.*, 51–56.

Rodriguez-Otero, J. L, Hermida, M. & Cepeda, A. (1994). Determination of fat, protein, and total solids in cheese by near-infrared reflectance spectroscopy. *J. AOAC International*, **78**, (3), 802–806.

Skjöldebrand, C. (1991). Moving from art to science in food processing. *Food Technology International Europe*, 115–118.

Skjöldebrand, C., Janestad. H. & Sundström, B. (1993). Mathematical computer simulation of food processes. *Food Technology International Europe*, 91–93.
Skjöldebrand, C. (1995). The future for on-line quality control in the food industry. *Food Technology International Europe*, 115–118.
Tinham, B. (1996). Much, much more than SCADA power. *Control and Instrumentation*, Jan, 31–32
Wallins, P. (1995). Advanced food manufacturing technology. *Food Technology International Europe*, 112–114.