ASPECTS OF RAPID ANALYSIS IN THE FOOD FACTORY

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ABSTRACT
Rapid analysis and extensive process control by use of sensor technology is essential to food processing technology. It is a prerequisite for improvements in product quality and manufacturing costs as present controls widely rely on sensory evaluation or laboratory analyses.

The present paper reviews current developments in sensor technology determined for use in the food industry. It describes the requirements of the food industry to sensors as well as the advantages that can be achieved by use of sensor technology. In addition sensors are classified in 1) in-line non-contacting, 2) in-line contacting, and 3) on-line. Examples of each group are presented and their impact on process control is discussed.

INTRODUCTION

Development and implementation of rapid analysis for the food factory require several more considerations than to those compared for the food laboratory. The analytical sensors must have a high speed of response, be insensitive to temperature, humidity, and other environmental interference and be constructed to withstand the extensive cleaning and sterilization which take place in food plants.

In addition, process control in the food factory is much more complex and difficult than in any other major industry. First of all, the food industry handles a large number of different, complex and variable raw-materials. Secondly, a large range of suitable sensors for measuring product quality does not exist (1,2,3). Sensors for primary measurements such as temperature, weight, pressure, flow have reached an acceptable st and are widely used within the f industry. However, when it comes more complex parameters such as co tent of nutritional components (p tein, lipids, carbohydrates etc microorganism, colour, and text traditional laboratory methods sensory evaluation are still the o reliable way of adequate process c trol.

During the last 5-10 years a limi number of process control devi have been implemented in the f industry. On-line measurements moisture content in cereals and fl by means of near infrared reflect (NIR) is one example (4,5). Anoth is the in-line measurements of colo in cereals, fruits and vegetabl (6). However, the number of sens and their impact on process cont within the food industry is sti limited although it is recogni that sensors are the prerequisite automation in the food industry.

The evident gap between the need sensors and their availability several explanations. It is very c plex and difficult to describe formulate the desired analyses (qu litative or quantitative) within food industry. Consequently, curr and potential manufacturers of sens lack exact information on the need It is more simple to manufacture s sors for the well understood pet chemical industri. Further and m important is that insufficient re search has been devoted to underst the relation between food and vari sensors techniques (f.ex. electrom netic radiation of any kind). On the information is brought to an el trical signal, analog or digital, is rather simple to utilize the formation in a process control.

The present communication will the fore concentrate mainly on reviewin current and potential sensors and a lesser extent on how these can integrated in an overall regulat mechanism of the food plant.

ENVIRONMENT IN THE FOOD INDUSTRY

In the past several attempts have been made to adapt off-line laboratory analyses to the industrial situation. Many of these attempts have failed due to one or more of the reasons listed in Table 1.

Table 1

Senors Characteristics of Importance for the Food Industry

- Speed of response
- Accuracy of repeatability
- Lifetime
- Capital and running costs
- Physical robustness
- Service requirements
- Insensitivity to range temperature and other interference
- Calibration ability

For example a glucose sensor (7) works satisfactorily in the laboratory but when implemented in an industrial fermentation tank, environmental factors disturb its signal. It is therefore of paramount importance that the above listed factors are included in the development and design program of sensors for industrial purposes.

ADVANTAGES OF SENSOR TECHNOLOGY

The impact of extensive process control by sensors is substantial. Product quality can be improved by rejection of undesired items and thus result in higher consumer acceptability. Furthermore, accurate control of weight, moisture, protein, and other relevant parameters will tend to increase the overall product yield. This reduces severe losses due to inadequate yield control in many food plants.

The food industry is very labour intensive and major parts of the industry are very capable of reducing labour costs by introduction of sensor technology. It also reduces breakdown time caused by operator errors. Finally and most important is the improvement in the overall plant performance and its competitiveness.

SENSOR CLASSIFICATION

Different sensor concepts are outlined in figure 1. The "ideal" sensor provides a 100 per cent inspection of the material. It is in-line, non-invasive, and non-contacting to the material stream. This type of sensor (here classified as in-line, non-contacting) would imply the use of some form of radiation and real time detectors in the form of protodiodes, line-scan or video camera.

The second group of real time in-line sensors includes invasive sensors i.e. sensors that are in a direct contact with the material. Typical examples are biosensors for use in the fermentation industry.

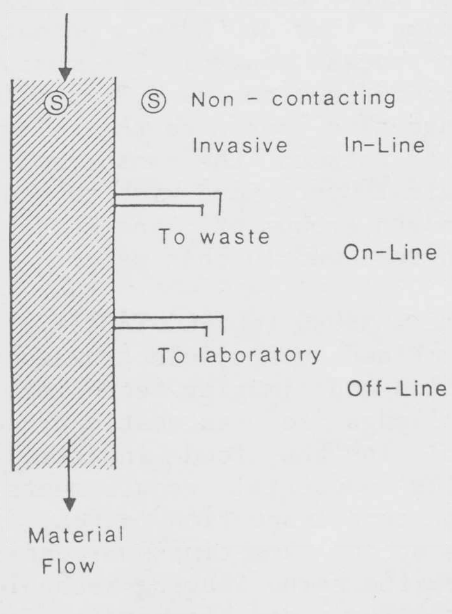


Fig. 1 Sensor classification

The third group includes sensors that are brought in contact with a minor part of the material. This could be accomplished by placing the sensor in a loop of the material stream or by using a side-arm of the material.

very large volume of data represente in an image. Typically in the orde of 256 K bytes.
An image analysis system is shown i figure 2.

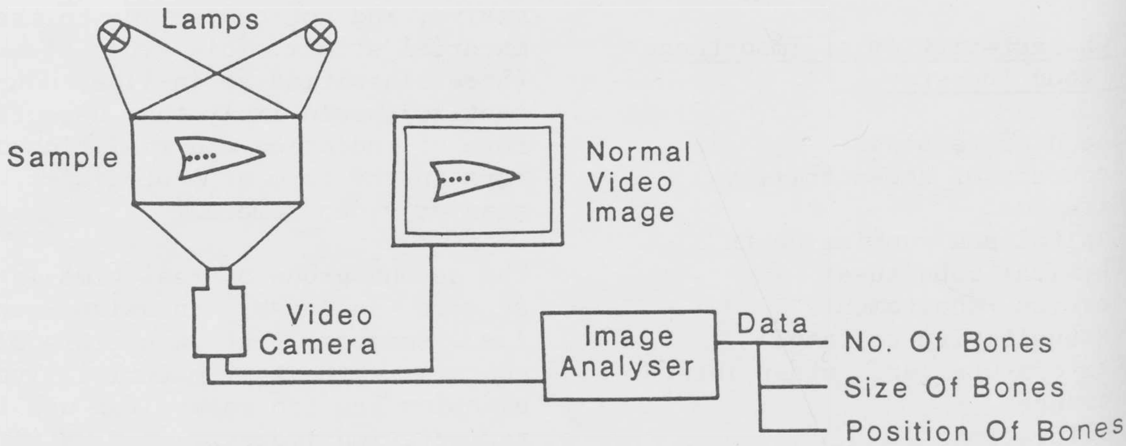


Fig. 2 Schematic diagram of video image analysis system

Typical examples of on-line is HPLC, GC, MS, and FIA. Although the response time of these sensors is not strictly real time they do have a potential use in process control. The most important is not necessarily absolute response time but more the relative dynamics between the sensor and the biological system one wish to measure. The fourth group, off-line sensors, is not reviewed in this paper.

IN-LINE SENSORS (NON-CONTACTING)
The combined use of electromagnetic radiation and imaging technology is a challenge for automatic process control in the food industry. It fulfills industrial requirements of 100 per cent inspection in real time and is at the same time non-contacting. Furthermore, imaging technology is ideal for feed forward or feed backward information (8).

Imaging technology (or image analysis) has been possible for over twenty years but it is only during the current decade that significant numbers of industrial applications have been practicable. The reason for the delay in industrial applications is the

The sample of interest is illuminate by electromagnetic radiation (visibl UV, IR or X-ray) and the resulti image is captured by a video camera.

The video signal is then digiti and stored for further processing When digitized the image can be pro cessed in a number of ways dependin on the actual situation.

DETECTION OF FISHBONES
The presence of bones or bone frag ments of a specified size and sha in "boneless" fillets is regarded a a critical defect. This critical de is often the cause of rejections o boneless fillets or fillets blocks i international trade, therefore caus severe economic losses for the pro ducer. When exited by light of 340 n (fig. 3) bones of fish exhibit a dis tinct autofluorescence with maxim fluorescence at 390 nm - (fig. (9,10). The strong autofluorescen of fishbones at 390 nm is consta for various species, including co whiting, haddock, plaice, and salmo

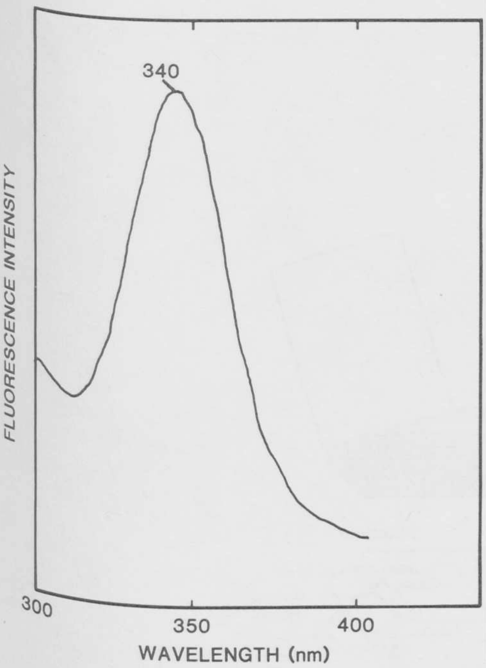


Fig. 3
Excitation spectrum of bones excised from sample of cod (9).

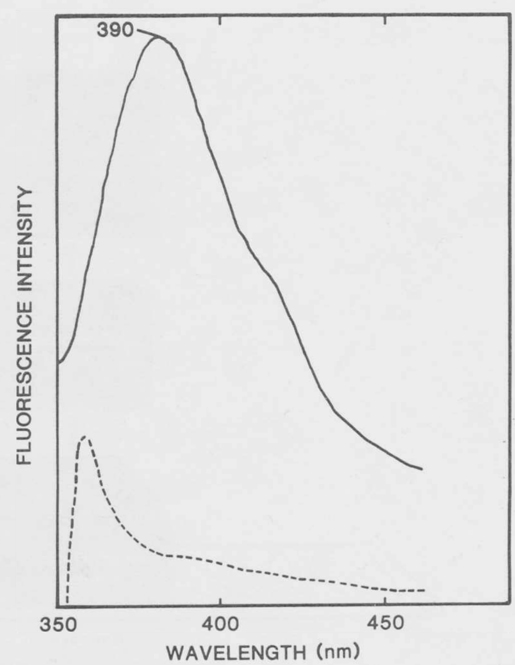


Fig. 4
Emission spectra of bones (___) and flesh (---) (9) excised from a sample of cod obtained at 340 nm excitation (9).

This fluorescence phenomenon of fish-bones has been used to develop an automatic inspection system for bones in fish fillets (fig.5) (11). The system consists of four basic components: The conveyor, the electrooptical scanner with light sources and camera, the image analyser, and the manifold. The conveyor belt feeds fish fillets through the optical station. An advanced light source illuminates the fillets and the resulting image is captured by a videocamera. The video image computer instantly calculates the number of bones, their length, width and position. The fillets are then classified into two groups based upon pre-set acceptance limits for the number of bones. The overall capacity of the system is 60-90 fillets per minute.

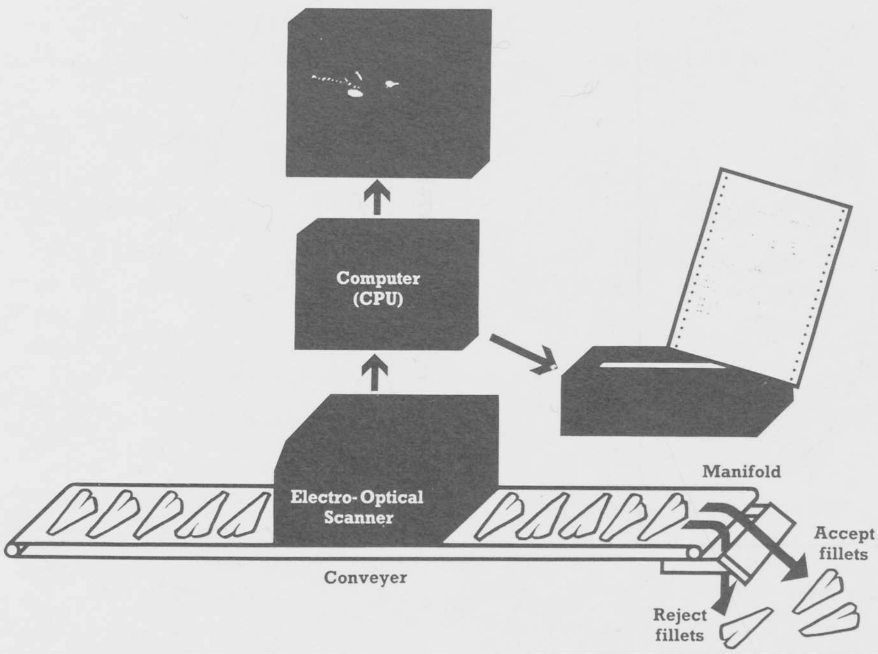


Fig. 5 Schematic diagram of image analysis system for detection of bones in fish fillets.

The fishbone Detector enables the fishing industry to produce fish fillets with a minimum of bones and human error is virtually eliminated by accurate video assessment and solid state electronics.

MEASUREMENT OF FAT AND CONNECTIVE TISSUE IN MEAT

In recent years processing and development of new products has been an expanding area in the meat industry. Thus the demand for accurate control of composition in raw materials and final products has increased. Furthermore, commercial scale production deals with large quantities of material and to adequately regulate production, the analyses for meat, fat, and connective tissue has to be an in-line process. The traditional chemical analyses do not fulfill the requirements of the meat industry. Recent research has disclosed that fat, connective tissue, bones, and meat from pork, cow and poultry exhibits characteristics fluorescence spectra when excited by light of 340 nm (9). Figure 6, 7, and 8 show fluorescence spectra of bovine meat, porcine cartilage, and bovine fat. It is evident that bovine meat almost lack fluorescence whereas its fat exhibits two distinct fluorescence peaks at 390 nm and 475 nm, and cartilage from pork shows a strong fluorescence peak at 390 nm.

The chemical basis for the fluorescence characteristics is not yet established but recent microscopic studies of connective tissue indicate that the fluorescence is related to elastin fibres.

Recently, this invention has been used to develop a system for in-line measurement of fat/lean ratio in meat products (12, 13). The system is based upon video images analysis, and its construction is very similar to the Fishbone Detector. Comparison of fat content determined by video image analysis and fat determined by dissection, planimetry, and chemical analysis revealed a good correlation

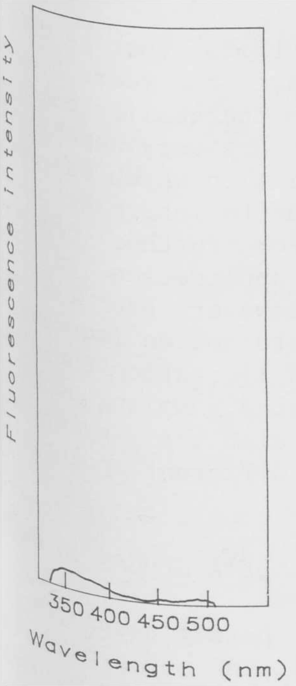


Fig. 6

Emission spectrum of bovine meat obtained at 340 nm excitation (10)

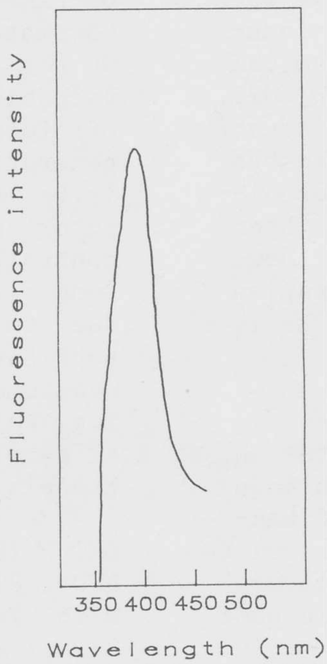


Fig. 7

Emission spectrum of porcine cartilage obtained at 340 nm excitation (10)

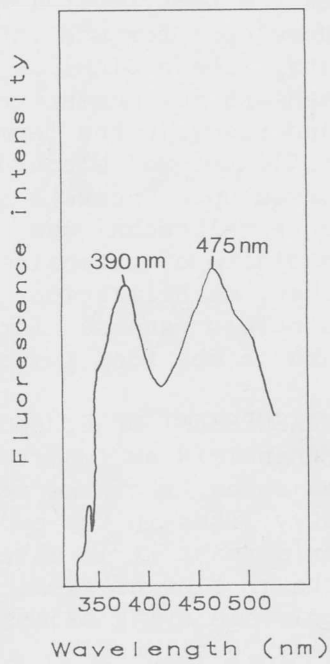


Fig. 8

Emission spectrum of bovine fat obtained at 340 nm excitation (10)

COLOUR MEASUREMENT OF FRUITS AND CEREALS

In the processing and marketing of foods, colour is of paramount importance. The consumer expects a minimum amount of colour defects in high grade products. It is therefore evident that in-line colour measurement has been a subject of extensive research in the past.

By using line-scan camera or photodiodes in combination with colour filters, the English company, Sortex Ltd., has developed a wide range of in-line inspection systems for colour sorting. Some of their developments include a system for sotring discoloured or unriped peaches at a capacity up to 25 tons per hour (6). It also includes a sorting machine for rejection of discoloured rice seeds.

IN-LINE SENSORS (CONTACTING)

The second group of in-line sensors includes those which are directly or indirectly in contact with the food item. They must be real time sensors with possible feed forward or feed backward information. In addition, the sensors must be constructed to withstand the often hardeous environment and cleaning/sterilization procedures.

In the past several sensors have been developed for use in the food industry. These include electrochemical sensors for measurements of pH, 02, and redox in the fermentation industry (14). Enzyme electrodes and sensors based upon accustical and piozeelectrical techniques have also been subjects of extensive research. However, stabilization and calibration problems have so far limited their use in the food industry.

MEASUREMENT OF ETHANOL
Ethanol is an important parameter in major parts of the fermentation industry. Thus in the production of baker's yeast it is essential to regulate the in-flow of substrate very accurately since its excess results in poor yeast quality.

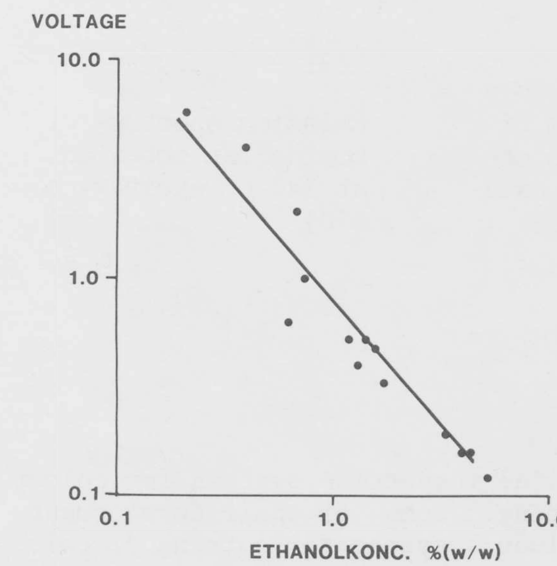


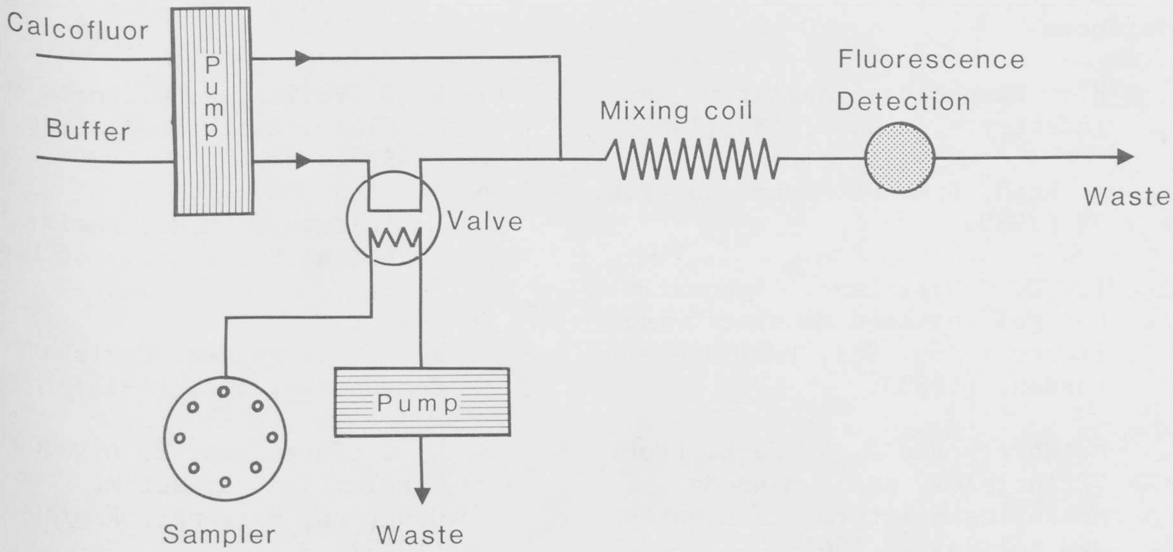
Fig. 9
Results of ethanol sensor at low ethanol concentrations (16).

Figure 9 shows results obtained with a newly developed ethanol sensor (15, 16). The active part of this sensor is a semiconductor which changes its electrical characteristics in presence of flammable or reducing gasses. The semiconductor is placed behind a siliconemembrane which enables the sensor to be placed in the headspace of a fermentation tank.

ON-LINE SENSORS
Chromatography methods such as HPL GC or GC/MS have for years bee valuable tool in the quality contr of foods. They are very capable generating information which can e ly be transferred to integrated co puter systems for further proce control. Their application in t food plant has, however, been limit due to high costs and environment sensitivity. This limitation could overcome by advanced sampling techn logy which could also imply syncron ed sampling at different points the plant.

DETERMINATION OF BETA-GLUCAN IN BE AND WORT
High levels of beta-glucans (1 - 3), (1 - > 4) - beta - D-glucans wort and beer cause filtering probl for wort and beer as well as prec pitates in the finished beer.

Traditional measurement implies pr cipitation with ammoniumsulphat This method is laborious and time consuming and thus not suitable f quality control. Recent research the Carlsberg Research Center ha however, resulted in a new meth suitable for on-line analysis in t brewery. The method uses the increa in fluorescence intensity when t fluochrome-calcofluor binds to bet glucans in solution (19, 20) and fl injection analysis (FIA) (21). Figu 10 shows a drawing of the system. I dividual samples are injected in the system via the valve and the a tosampler.
The system is very compact and sui able for placement at the brewe plant. Figure 11 shows recorder ou puts of the beta-glucan analyse Response time is in the order of sec.



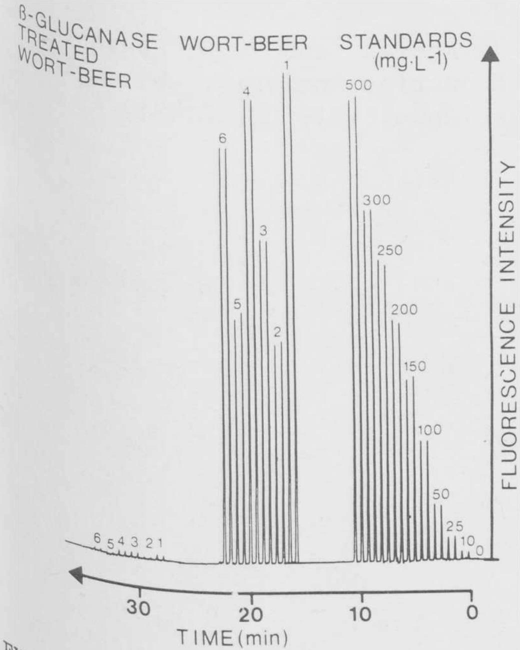


Fig. 10

Diagram of the apparatus used for the beta-glucan analyser based on flow injection analysis (FIA) (20).

Fig. 11

Recorder output of the betaglucan analyser showing the results of standard samples and beer and wort samples before and after treatment with beta-glucanase preparation (20)

FUTURE TRENDS

The ability to handle plant and process information is rapidly surpassing the ability to generate it. Future research and resources should therefore be allocated to a better understanding of the interface between foods and various sensor techniques. Combined use of electromagnetic radiation and imaging technology is, in my opinion, a challenge for improved process control in the food industry. Interaction between food and radiation generates tremendous amount of information and imaging technology can assure that food items will be analysed and treated as individuals. Often we may realize that the information is not univariate but multivariate. But, this could be overcome by Once the image analysis data is extracted it can be used for several applications. Mainly we have seen its potential in integrated process control but a future and very important application is as guidance for robots.

The Fishbone Detector provides exact information of number of bones, their size and position and by transferring this information to a robot mounted with a water jet it becomes possible to produce boneless fillets fully automatic. Similar conclusions can be drawn for the meat industry where combined use of imaging technology and robots can result in a concept of an automatic processing system.

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