AUTOMATION OF FOOD PROCESSING

Gunasekaran, **S**
Department of Biological Systems Engineering, University of Wisconsin-Madison, USA

Keywords: Computer aided design, computer integrated manufacturing, computer vision system, flexible manufacturing systems, fuzzy logic, neural networks, productivity, profitability, quality, robot, sensors.

Contents

Summary

The food industry has traditionally lagged behind other industries in adopting new technology, and plant automation is no exception. However, rapid advances in computer technology and heightened expectations of consumers and regulatory agencies for improved food quality and safety have forced the food industry to consider automation of most manufacturing processes. Though the food industry presents many unique challenges to complete automation, the industry has been successful in putting many automatic processes into place. The next significant development will be to integrate these "islands of automation" into an overall system of plant automation, from receiving

raw materials to shipping finished products. New technological tools such as computer vision, expert systems, computer integrated manufacturing, flexible manufacturing systems, systems engineering, etc., have enabled integration of many batch operations into an overall manufacturing system design to provide on-line and continuous control capability. This trend will continue at an even faster pace in the next several years.

1. Introduction

The automation of manufacturing plants has been actively pursued for more than 50 years. And it will continue to be so, even more aggressively, during the next 50 years. The increased zeal in industrial automation is mainly due to the explosive growth in computer hardware and software technology. As computers invade almost every aspect of our daily lives, the public at large has come to expect a high level of automation in every facet of the manufacturing processes.

The extent of industrial automation depends a great deal on the type of industry. The automobile and semiconductor industries represent the most mature in adopting plant automation principles with nearly all processes having been automated and fairly well integrated. At the other end of the spectrum is perhaps the food industry, representing lower levels of automation, which has traditionally lagged behind in adopting technological advances. The current level of automation in the food industry has been described as "islands of automation". Nonetheless, the food industry now ranks among the fastest growing segments for plant automation. For example, the food industry is among the top ten in using machine vision technology, a key component in plant automation. However, most systems are isolated, batch-type operations that target a specific task. In order for automation to be successful, it must be integrated into the overall manufacturing system design and provide on-line, continuous control capability.

2. Why Automate?

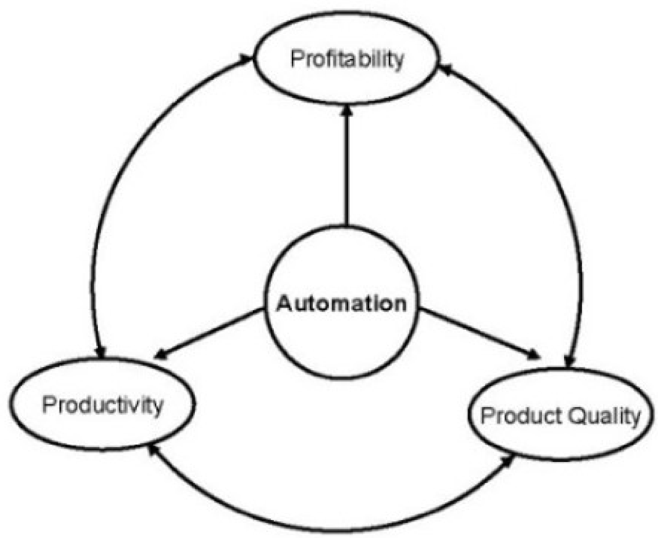

Figure 1. Plant automation can improve productivity, product quality, and profitability.

The need to automate industrial processes is driven by several key requirements for competitive success and, in some industries, viability of the manufacturing plants. They can be listed as those needing to improve productivity, product quality, and profitability. This is depicted schematically in Figure 1.

2.1. Improved Productivity

Plant productivity may be defined as the quantity of end products manufactured per unit of operating parameters – plant size, number of workers, time of operation, etc. Therefore, productivity is directly related to how efficiently the input resources are utilized in translating them into marketable end products. This is possible because automation allows for efficient scheduling of work flow and labor use. The ability to maintain good records and information about past processes can clearly highlight areas that can be targeted for a more efficient allocation of resources. One plant reported a 30 percent increase in plant productivity by using three discrete microprocessor-based controllers designed to perform all continuous loops involving complex, integrated algorithms, valve interlocking, and some sequencing. Similar controls can also be used to optimize formulations, production scheduling, and process modeling.

2.2. Improved Product Quality

Quality assurance is one of the most important goals of any industry. The ability to manufacture high quality products consistently is the basis for success in the highly competitive food industry. High quality products encourage customer loyalty and results in an expanding market share. Quality assurance methods used in the food industry have traditionally involved human visual inspection. Such methods are tedious, laborious, time-consuming, and inconsistent. As plant productivity increased and quality tolerance tightened, it became necessary for the food industry to employ automatic methods for quality assurance and quality control. In fact, this aspect of food manufacture is one of the areas that has received the most attention in terms of automation. Thanks to advances in computer vision technology, substantial changes have been implemented in food plants to facilitate automatic food quality evaluation.

2.3. Improved Profitability

Increased profit is perhaps most important from the perspective of management. Improved profitability not only adds to shareholder value but also allows management to invest strategically in expanding plant operations, increasing product lines, further improving product quality, etc. As discussed previously, automation helps to improve productivity and product quality. Both of these contribute directly to improved profitability.

Another important factor that makes automation extremely critical for the food industry is the need to comply with food safety and environmental regulatory agencies. Computer-controlled plant operations provide virtually unlimited opportunities to maintain records of all events in plant operation. Furthermore, the ability to collect, store, retrieve, and process data allows plants to identify areas of concern. This information can then readily be used for improved productivity, product quality, and profitability. For example, generating ingredient usage reports helps in active inventory control. Such reports can be generated for daily, weekly, monthly, and yearly use to give a quantitative picture of comparisons necessary for future planning. Smart systems can also monitor and record periodic and transient variations in product variables. An operator can use these records to monitor real time, alter set points, change system configurations, perform testing, etc.

3. Uniqueness of the Food Industry

One of the most important reasons for increased interest in automating the food industry is its cost structure. Food processing is highly labor-intensive, with labor costs at anything up to 50 percent of the product cost. Improving productivity and reducing labor costs will therefore have a significant impact on profitability. Much of the manual work in food processing requires rapid, repetitive, and monotonous movement and, consequently, low levels of motivation are often found. This leads to poor quality control and a high incidence of industrial accidents. The repetitive nature of the work has resulted in a substantial medical cost to the industry. Automating repetitive tasks will improve quality control and efficiency and reduce the high level of accidents.

One of the most important obstacles in the automation of food manufacturing is the biological variation in size, shape, and homogeneity of the raw materials (see *Engineering Properties of Foods*). Some materials (e.g., dairy) lend themselves readily to automatic processing because the raw material (milk) can be handled in bulk. Accordingly, the dairy industry is among the most automated. But materials such as fruits, vegetables, meat, etc., need to be handled on a more individual unit basis. This has hampered automation tremendously. Thus, food industry automation requires a level of flexibility uncommon to other mature industries.

Additional problems are due to the lack of complete physical and chemical characterization of foods. Even when complete information is available, the raw material or the end product can change. Changes in the raw material arise from the introduction of new varieties and/or variations in agronomic conditions. The end product can change due to continual reformulation of product lines to gain market share. Application of computer vision technology is substantially changing the quality evaluation tasks in the food industry.

In addition to a products physical characteristics, factors such as microbiological and biochemical concerns place additional limitations on handling and processing procedures employed. The mechanical, thermal, and sensory properties of food materials (see *Engineering Properties of Foods*, and *Sensory Evaluation*) also require specific limits on the nature and extent of processing steps. These constraints complicate process automation.

Materials that are not well defined in size or shape are often presented in a random, unconstrained orientation. They must often be handled carefully to prevent damage and thus challenge the capabilities of current technology.

Therefore, there are few examples of "hard" automation – types that give little or no allowance for variability. For example, automatic equipment for peeling fruit still relies heavily on standard shapes and sizes. Some excellent examples of automation include processing and packaging of fresh eggs and dairy products. Although most baking is done in automatic ovens, baked products are still manually graded and packaged. In the poultry industry, automation is possible as long as the birds are graded into different weight classes. Development in this industry can offer automatic slaughtering, plucking, washing, decapitating, and eviscerating of poultry carcasses at a fairly high rate. Another commercial operation is automatic fish processing. An automated butchering system separates the edible loin portions of transverse tuna slices. Each slice is scanned by a computer vision system, and control signals are transmitted to a cutting arm that then separates the edible portion. Vision systems have also been successfully used in automating sweet corn processing.

Food plant floors are rather hostile to electronics and computers. Temperature extremes, vibration, dust and, especially wash down, can all interfere with the operation of computer hardware. Lower levels of hardware such as controllers are not generally affected by these problems because they are specifically designed for plant use. However, computers are more prone to damage. Processors wanting computers on plant floors should either buy units specifically adapted for ruggedness, which cost two to three times that of regular units, or else locate all computing equipment in an industrial enclosure away from the plant floor. Obviously, cost and convenience should be weighed carefully to avoid expensive computer downtime when proper precautions are not taken.

4. Tools of Automation

4.1. Computer Vision Systems

Computer vision is the science that develops the theoretical and algorithmic basis by which useful information about an object or scene can be automatically extracted and analyzed from an observed image, image set, or image sequence.

An image can be defined as a spatial representation of an object or scene. A digital monochrome image is a two-dimensional (2-D) light intensity function denoted by I(x,y), where the value or amplitude of intensity I at spatial coordinates x and y is typically proportional to the radiant energy received in the electromagnetic band, to which the sensor or detector (camera) is sensitive in a small area around the point (x,y). As far as the computer is concerned, the image is a matrix x,y of numeric values, each representing a quantized image-intensity value. Each matrix entry is known as a pixel (short for picture element). The total number of pixels in an image is determined by the size of the 2-D array used in the camera. The intensity of the monochrome image is known as the gray level. The influence of an object's size, shape, position, orientation, and other attributes from the spatial distribution of gray levels requires the capability to infer which pixels belong to the object and which do not. Then, from the pixels belonging to the object, it requires the capability to identify those object features of interest. Many algorithms and processing methods have been developed to translate the gray levels of a pixel in a manner that accentuates desired features.

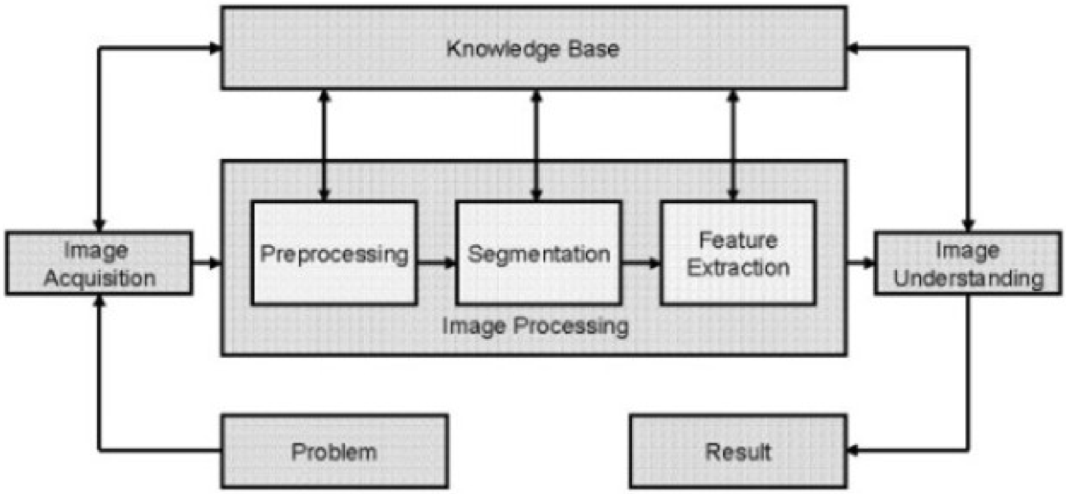

Figure 2. Essential steps in computer vision system application.

In general, a machine vision system is used to measure some aspect of the results of the manufacturing process (e.g., shape, size, texture, location) that is indicative of the accuracy, efficiency, or quality of the process. The measured parameters can then be used as feedback in a real time control loop that optimizes the manufacturing process through variations in process parameters (speed, temperature, flow rate, etc.). The essential steps in such a process are image acquisition, image processing, and image understanding (Figure 2). The image-processing step involves several key operations such as pre-processing, segmentation, and feature extraction. The image-processing step relies heavily on the knowledge of the product being evaluated and the nature of the defect or quality attributes of interest. Together, they facilitate image understanding and enable final decisions to be made.

Computer vision applications currently range from simple inspection to vision-guided robotic assembly. Most practical applications can be grouped into six general categories:

- Gauging – performing precise dimensional measurements.
- Verification – qualitatively ensuring that one or more desired features are present and/or undesired features are absent.
- Flow detection – finding and discriminating unwanted features of unknown size, location, and shape.
- Identification – determining the identity of an object from symbols, including alphanumeric characters.
- Recognition – determining the identity of an object from observed features.
- Locating – determining the location and orientation of an object.

Some key requirements in selecting appropriate computer vision follow:

- Speed of operation – the system must operate in real time, i.e., at production line speed.
- Robustness – the ability to function properly in a food plant environment.
- Tolerance – the ability to tolerate acceptable variations in the product.
- Accuracy – the ability to identify required features with a high level of accuracy.

- Flexibility – the ability to allow for changes in set points, operating algorithms, controls, etc.
- Reliability – the ability to perform a variety of inspection tasks consistently and repeatedly over a long period of time.

Due to advances in electronics and computer technology, vision systems can be installed in almost all food plants for a cost-effective quality evaluation/control operation. However, vision systems must be carefully designed around the particular characteristics of products being inspected so that they perform reliably under plant conditions. Significant research and analysis is necessary to determine the best method for enhancing and detecting product defects. This means pre-testing a large number of representative products with required defects or features.

Recent developments in vision systems include color image processing and three-dimensional (3-D) image processing. These developments offer additional benefits, especially for more challenging inspection tasks. Computer vision systems for analyzing on-line or moving scenes are also being designed for different applications. Input to a dynamic or moving scene analysis is in the form of a sequence of image frames taken from a changing world. The camera used to acquire the image sequence may also be in motion. Each frame represents an image of the scene at a particular instant. Changes in a scene may be due to motion of the camera or the objects, illumination changes, or changes in an object's structure, size, or shape. It is usually assumed that changes in scene are due to camera and/or object motion. A system must detect changes, determine motion characteristics of the observer and objects, characterize the motion using high-level abstraction, recover the structure of the objects, and recognize moving objects.

Depending on the design of the imaging system, different image processing techniques are required. In the food industry, the most common design is that of a stationary camera and moving objects. If a frame sequence is acquired at a rate such that no dramatic change takes place between two consecutive frames, then no abrupt change in motion can be observed for most physical objects. This is the basis for nearly all on-line applications currently available in the food industry. The important factor, then, is to set the image acquisition rate fast enough to minimize image blur so that an analysis of image data can take place frame-by-frame. Real time image processing boards and real time processors are available to assist in on-line real time computer vision applications. Figure 3 depicts an on-line product quality evaluation and control system using a computer vision system.

For a continuous stream of material flowing along a conveyor belt, a computer vision system can be designed using a line-scan camera for image acquisition. A line-scan camera contains a one-dimensional array of photosensitive sites. The line-scan camera is suitable for fairly rapidly moving object scenes. In addition to higher speeds, line-scan cameras offer high resolution and the ability to handle infinitely long image scenes. A new breed of cameras, known as time-delay and integrated cameras, are line-scan cameras, which use charge couple device image sensor technology to gain speed or increase sensitivity up to 100-fold (that of conventional cameras) while providing exceptional spatial resolution.

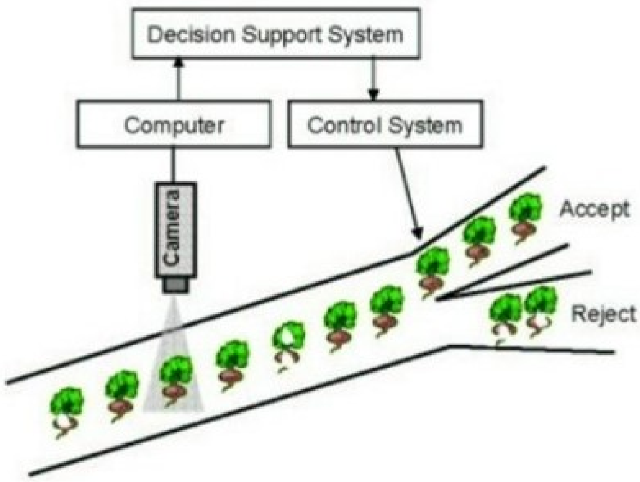

Figure 3. Schematic representation of on-line food quality evaluation using a computer vision system.

General requirements for on-line applications are throughput, speed, accuracy, consistency, durability, diversification, flexibility, and adaptability. Considerations of these conditions and constraints must be taken into account at all stages of system design and development. Speed of evaluation is perhaps the most striking requirement. It has been estimated that an on-line apple grading system may need to examine at least 3600 points/min. Several commercial systems are being used to examine 3.5 million pieces of fruit (apples, oranges, etc.) in an 8-h day. Another on-line fill-height inspection system has been reported to handle speeds of up to 1400 bottles/min.

Computer vision technology is becoming an integral part of the food industry's move towards automation. The presence of a machine vision system on a production line has come to represent an unmistakable demonstration of an industry's commitment to quality.

-
-
-

Bibliography

Asai K. and Takashima S., eds. (1994). *Manufacturing Automation Systems and CIM Factories*. New York: Chapman and Hall. [Describes plant automation in the context of computer integrated manufacturing and robotics].

Biekert R. (1998). *CIM Technology Fundamentals and Applications*. Tinley Park, IL: The Goodheart-Willcox Company, Inc. [Detailed description of computer integrated manufacturing technology].

Chilton's Food Engineering. Radnor, PA: Chilton Co. [A monthly publication that regularly carries articles related to plant automation in the food industry].

Food Processing. Chicago: Putnam Publishing. [A monthly publication that regularly carries articles related to plant automation in the food industry].

Gunasekaran S**.** (1996). Computer vision technology for food quality assurance. *Trends in Food Science & Technology* **7(8)**, 245-256. [Review of applications of computer vision in the food industry].

Mittal G.S., ed. (1997). *Computerized Control Systems in the Food Industry*. New York: Marcel Dekker, Inc. [Presents several articles on various computer control systems and applications to the food industry].

Pinder A.C. and Godfrey G., eds. (1993). *Food Process Monitoring Systems*. New York: Blackie Academic and Professional. [Describes several food process monitoring systems suitable for automatic evaluation of many food processing operations].

Teixeira A.A. and Shoemaker C.F. (1989). *Computerized Food Processing Operations*. New York: Van Nostrand Reinhold. [Presents information on computer architecture and controls for food industry applications].

Biographical Sketch

Sundaram Gunasekaran is Professor of Food and Bioprocess Engineering at the University of Wisconsin-Madison. His research interests are in physical and rheological properties, non-destructive food quality evaluation, and value-added processing of food and biomaterials. He has published extensively in these areas and has been recognized with several awards and fellowships.