Advanced Manufacturing Systems in Food Processing and Packaging Industry

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Abstract. In this paper, several advanced manufacturing systems in food processing and packaging industry are reviewed, including: biodegradable smart packaging and Nano composites, advanced automation control system consists of fieldbus technology, distributed control system and food safety inspection features. The main purpose of current technology in food processing and packaging industry is discussed due to major concern on efficiency of the plant process, productivity, quality, as well as safety. These application were chosen because they are robust, flexible, reconfigurable, preserve the quality of the food, and efficient.

1. Introduction
Food industry is one of the biggest industries in the world. In 2011, Plunkett Research reports that the total sale of food products in US is about 1508.5 billion US Dollar. This is comprised of poultry, meat, crops, vegetables, agricultural products and etc. Key components of food industry success are its food processing and packaging operation. It becomes necessary for companies to discover ways to improve their productivity in terms of maintaining safety, using sustainable materials in packaging, implementing flexible and standardized technology, and maintaining good quality of foods [1]. Reducing wastes is important, while shortening lead times is the goal of achievement. Recent advances in engineering such as Radio Frequency Identification (RFID), nanomaterials [2], and fieldbus technology bring greater opportunities to the processing and packaging industry.

2. Background
Food processing is the methods and techniques used to transform raw ingredients into food for human consumption. Food processing takes clean, harvested or slaughtered and butchered components and uses them to produce marketable food products [3]. There are several different ways in which food can be produced which are one off production, batch production, mass production or just-in-time production [4]. Food processing is any deliberate change in a food that occurs before it’s available for us to eat. It can be as simple as freezing or drying food to preserve nutrients and freshness, or as complex as formulating a frozen meal with the right balance of nutrients and ingredients [5]. Processing also includes pre-processing and cleaning which sometimes is referred to as post harvesting processes [6].Traditional processing principles are based on thermal processing where the combination of temperature and time plays a significant role in eliminating the desired number of microorganisms from the food product without compromising its quality. Non-thermal processing
methods such as PEF (Pulsed Electric Field), UV (Ultraviolet), and Ozone yield products with more ‘fresh-like’ flavour than those produced by traditional thermal processes due to fewer chemical and physical changes although they are not effective in reducing the activity of bacterial spores [7].

The principal roles of food packaging are to protect food products from outside influences and damage, to contain the food, and to provide consumers with ingredient and nutritional information [8]. Traceability, convenience, and tamper indication are secondary functions of increasing importance. The goal of food packaging is to contain food in a cost-effective way that satisfies industry requirements and consumer desires, maintains food safety, and minimizes environmental impact. A great deal of automation strategies are constantly being utilized in every phase of processing and packaging. Due to limitation of feasibility study and research in food processing, most of the studies focus on trends in food packaging and materials [6].

2.1 Materials in Food Packaging

Papers and clothes are flexible, lightweight, less waste-to-discard packaging materials. Glass and metals have been used for high-value products and are corrosion resistant and stronger, respectively. Polymers (plastics) exhibit many desirable features like transparency, softness, heat seal ability and good strength to weight ratio [9]. The most commonly used plastics in packaging industry are based on petro chemical products such as polyethylene terephthalate (PET), poly vinyl chloride (PVC), polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyamide. However, they cause adverse effect (neither totally recyclable nor biodegradable) to the environment causing risk to human health or ecosystems [6]. There is an increasing demand for identifying biodegradable packaging materials and finding innovative methods to make plastic degradable. Biodegradation is the process by which carbon-containing chemical compounds are decomposed in the presence of enzymes secreted by living organisms. The use of bio plastic is to replicate the life cycle of biomass by conserving the fossil fuels, carbon dioxide and water production.

2.2 Smart Packaging

Smart packaging purpose is to add extra features to the food and also benefits the consumers. It deals with the mechanical, mechanical, chemical, electrical and electronically-driven function that enhances the usefulness of the food products in a something that can be measure. Various aspects of smart packaging are available for instances; time-temperature food quality labels, usage of self-heating or self-cooling containers integrated with electronic displays indicating important information on nutritional qualities and expiry dates. One of the good examples are the use of self-heating coffee container based on CaO exothermic reaction [10] and the introduction of RFID (Radio Frequency Identification) tag in an conventional package. The key functionality is electronic and the major beneficiaries are the stakeholders along the entire supply chain. There have been an increasing numbers of researches on application of nanocomposite materials which scale from 1-100 nm [11]. The advantage of using nanocomposite materials is mainly to improve the mechanical and oxidation stability of the foods. The famous nanocomposites used are (i) Polymer clay nanoclay (ii) Silica nanocomposites of nanosilver. The benefit of nanoclay in polymer is increased stiffness, strength and smaller cell size. Furthermore, researchers at University of Connecticut are developing nanoparticle films with embedded sensors in packaging in order to detect pathogens. This make the consumers possible to detect food contamination by monitoring colour change in packaging [12].

3. Manufacturing Systems in Food Processing and Packaging

Manufacturing systems today is beyond our imagination for few decades ago. The vast development and research in manufacturing systems brings benefit to the food processing and packaging industry. Advanced manufacturing systems include machineries and systems, automation, SCADA and DCS as well as its systems integration. Machines in food industry play major part in producing high return of investment without compromising quality in food. Moreover most of the machines are controlled by microprocessor, programmable logic controller or monitored remotely by the presence of SCADA. To
make it more efficient in producing massive amount of food products, the integration of machineries and systems must be easily adaptable to changeover with minimal time consume in tool changing. Most systems in food processing and packaging include cartooning machines, wrapping machines, labellers, shrink machines, cooling and drying machines, feeding and placing machines, inspection and detection machines as well as cleaning and sterilizing machine [6]. There have been strict regulations regarding food safety and hygiene due to numerous cases of food irradiation. The food processing industries have to take serious on the food irradiation issues by designing equipment and machine to cater the customers need.

3.1 Automation
Rising labor cost, health and safety issues lead to the application of robot and automation in food processing and packaging. The need to automate food processing and packaging activities is driven by several key requirements for competitive success and in some industries, viability of manufacturing plants. The advantages of automation are to improve productivity, product quality and profitability.

![Figure 1](image_url)

**Figure 1.** Plant Automation can improve profitability, product quality and productivity [13]

Productivity is directly related to how efficiently the input resources are utilized in translating them into marketable end products [13]. This is promising as a result of automation allows efficient scheduling of work and labor use. The food processing and packaging industry can preserve good records and data about past processes and significantly spot areas that can be targeted for more efficient allocation resources. According to research by University of Wisconsin-Madison, USA, an average of 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.

Quality assurance by far is the aim of any industry in the world. The capacity to process and package high quality foods consistently is the key for success in vastly competitive food industry [13]. Traditionally, the quality assurance activities in the industry are based on human visual inspection. This method is outdated and requires 100 percent involvement of human thus effect the total cycle time. As productivity increased vigorously, the quality supposed to be improved simultaneously. For example, inspection of the quality of potatoes and its sizes is achievable through the use of real time mathematical computer method using machine vision [14]. The overview of the system can be visualised in Figure 2 where the image acquisition process, pre-processing, thresholding, size measurement, defect detection and output for standard potatoes were taken place.
Figure 2. Potatoes machine vision inspection system’s overview [14]

Although this system is still in research and developing stage, the benefit of the implementation of the system in large scale food processing and packaging industry can substantially improve quality of the end products.

The third aspect that contributes to the implementation of automation in food industry is the profit. Increased profit is the key element of business stability in eye of the management. With the improved in the productivity and quality, the profit margins will also be improved concurrently. The practice computer-controlled plant operations offer unlimited opportunities to maintain records of all events in the operations. For instance, generating usage reports helps in active inventory control. It can help to give quantitative picture of comparisons necessary for future planning [13]. This information can then readily be used to improve productivity, quality as well as profit.

3.2 Advanced Fieldbus Technology

Most of major industry in this world such as oil and gas, power generation, and waste management industries have adopted the advanced fieldbus technology into its automation and control systems since its existence. However, the implementation of this excellent technology into food processing and packaging industry as a whole is still in preliminary stage. Fieldbus is a control networking system, used for connecting field devices such as sensors, actuators, regulators, controllers, and man-machine interfaces with each other for factory automation [15]. It can be considered as sophisticated, compact and advanced digital communication method that reduce the wiring costs. Before the introduction of fieldbus technology to the automation world, most of food processing and packaging industry use conventional 4 to 20mA systems into its sensors and actuators network. The advantage is that the cost of installation is lower in low scale network due to fewer numbers of sensor and actuator. However, in mass production of food, the usage of conventional network system limits the performance thus affects the productivity. Table 1 describes the comparison between fieldbus system and conventional system [15]. When dealing with processing and packaging industries, there is a need for minimal production cycles with high performance and efficiency. By implementing fieldbus controls, an average company can save around 55% capital costs [15]. Some of the well-known fieldbus standards are ModBus, PROFIBUS DP, PROFIBUS PA, DNP3, CAN Open, P-NET, EIB, DeviceNet, LonWorks, FOUNDATION Fieldbus, WorldFIP, AS-I, SMART Distributed Systems, SERCOS, Interbus, etc [16]. Table 2 summarize the fieldbus technical data available in the market.
| Fieldbus Technology | Technology Developer | Year Introduced | Physical Media | Max. Devices (Nodes) | Max. Distance | Primary Application |
|---------------------|----------------------|----------------|----------------|---------------------|---------------|---------------------|
| Arcnet              | Datapoint            | 1977           | Coax, twisted-pair, fibre | 255                | 400-2000 feet  | Assembly, packaging and materials handling machines |
| AS-I                | AS-I Consortium      | 1993           | Two wire cable | 32 without repeaters, 250 with repeaters | 1.2km, 13.2 km | Intelligent I/O modules, Process control |
| Bitbus              | Intel                | 1996           | Twisted pair | 30                  | 25-1000m      | Sensors, actuators, automotive |
| CANOpen             | CAN in Automation    | 1995           | Twisted pair, optional signal and power | 99                 | 250-1000m     | Mission-critical, plant-wide networking of PCs, PLCs |
| ControlNet          | Allen-Bradley        | 1994           | Coax, fibre | 64 per segment      | 3km           | Assembly, welding and materials handling machines |
| Data Highway Plus (DH+) | Allen-Bradley      | 1994           | Twinaxial     | 64                  | 500m          | Assembly, welding and materials handling machines |
| DeviceNet           | Allen-Bradley        | 1994           | Twisted pair for signal and power | 32 without repeaters, 250 with repeaters | 1.2km, 13.2 km | Remote I/O, data acquisition |
| Filibus             | Gespac               | 1995           | Twisted pair | 240/segment, 65,000 segments | 1900m         | |
| Foundation Fieldbus H1 | Fieldbus Foundation | 1995           | Twisted pair, fibre | 1024, more via routers | 185m (thin)   | |
| Foundation Fieldbus HSE | Fieldbus Foundation | 1992-1996      | Twisted pair, fibre, and radio | IS: 3-7, non-IS 128 | 500-1700m     | |
| Industrial Ethernet | DEC, Intel, Xerox     | 1976           | Thin Coax, twisted-pair, fibre, thick coax | 256                | 400m          | Assembly, welding and materials handling machines |
| Interbus-S          | Phoenix Contact      | 1984           | Twisted pair, fibre, slip ring | 32,000 per domain  | 2000m         | |
| LONWorks            | Echelon              | 1991           | Twisted pair, fibre, power line | 64 nodes, 126 addresses | 500m         | |
| Modbus Plus         | Modicon              | 1990           | Twisted pair | 32 per segment, 64 max | 500m per segment | |
| Modbus RTU/ASCII    | Modicon              | 1990           | Twisted pair | 250 per segment     | 350m          | |
| Profibus DP/PA      | Siemens              | 1995           | Twisted pair or fibre | 32 without repeaters, 127 with repeaters | 200m, 800m     | Inter-PLC communication, factory automation |
| Remote I/O          | Allen-Bradley        | 1980           | Twisted pair | 32 per segment      | 6km           | |
| SDS                 | Honeywell            | 1994           | Twisted pair for signal and power | 500m     | 500m         | Assembly, materials handling, packaging, sorting |
| Seriplex            | APC                  | 1990           | 4-wire shielded cable | 500+ devices >500 feet | 500+ devices >500 feet | |

Table 2. Fieldbus technical data [17]
| Fieldbus Technology | Technology Developer | Year Introduced | Physical Media | Max. Devices Nodes | Max. Distance | Primary Application |
|---------------------|----------------------|----------------|----------------|--------------------|--------------|-------------------|
| WorldFIP            | WorldFIP             | 1988           | Twisted pair, fibre | 64 without repeaters, 256 with repeaters | 2 km, >10 km | Real-time control, process/machine |
| Arcnet              | Datapoint            | 1977           | Coax, twisted pair, fibre | 255 | 400-2000 feet | Assembly, packaging and materials handling machines |
| AS-I                | AS-I Consortium      | 1993           | Two wire cable | 31 slaves | 100-300m | Assembly, packaging and materials handling machines |
| Bitbus              | Intel                | 1994           | Twisted pair | 32 without repeaters, 250 with repeaters | 1.2km, 13.2 km | Intelligent I/O modules, Process control |
| CANOpen             | CAN in Automation    | 1995           | Twisted pair, optional signal and power | 30 | 25-1000m | Sensors, actuators, automotive |
| ControlNet          | Allen-Bradley        | 1996           | Coax, fibre | 99 | 250-1000m | Mission-critical, plant-wide networking of PCs, PLCs |
| Data Highway Plus (DH+) | Allen-Bradley      | 1996           | Twinaxial | 64 per segment | 3km | |
| DeviceNet           | Allen-Bradley        | 1994           | Twisted pair for signal and power | 64 | 500m | Assembly, welding and materials handling machines |
| Fiibus              | Gespac               | 1994           | Twisted pair | 32 without repeaters, 250 with repeaters | 1.2km, 13.2 km | Remote I/O, data acquisition |
| Foundation Fieldbus H1 | Fieldbus Foundation | 1995           | Twisted pair, fibre | 240/segment, 65,000 segments | 1900m | |
| Foundation Fieldbus HSE | Fieldbus Foundation | Current        | Twisted pair, fibre and radio | IP addressing, essentially unlimited | 100-2000m | |
| IEC/ISA SP50 Fieldbus | ISA & Fieldbus Foundation | 1992-1996 | Twisted pair, fibre and radio | IS: 3-7; non-IS 128 | 500-1700m | |
| Industrial Ethernet | DEC, Intel, Xerox    | 1976           | Thin Coax, twisted pair, fibre, thick coax | 1024, more via routers | 185m (thin) | |
| Interbus-S          | Phoenix Contact      | 1984           | Twisted pair, fibre, slip ring | 256 | 400m | Assembly, welding and materials handling machines |
| LONWorks            | Echelon              | 1991           | Twisted pair, fibre, power line | 32,000 per domain | 2000m | |
| Modbus Plus         | Modicon              | 1994           | Twisted pair | 32 per segment, 64 max | 500m per segment | |
| Modbus RTU/ASCII    | Modicon              | 1994           | Twisted pair | 250 per segment | 350m | |
| Profibus DP/PA      | Siemens              | 1994           | Twisted pair or fibre | 32 without repeaters, 127 with repeaters | 200m, 800m | Inter-PLC communication, factory automation |
| Remote I/O          | Allen-Bradley        | 1980           | Twinaxial | 32 per segment | 6km | |
| SDS                 | Honeywell            | 1994           | Twisted pair for signal and power | 64 nodes, 126 addresses | 500m | Assembly, materials handling, packaging, sortation |
| Seriplex            | APC                  | 1990           | 4-wire shielded cable | 500+ devices | >500 feet | |
| WorldFIP            | WorldFIP             | 1988           | Twisted pair, fibre | 64 without repeaters, 256 with repeaters | 2 km, >10 km | Real-time control, process/machine |

3.3 Distributed Control System
Most of food processing and packaging industry mainly apply centralized control system on its automation. The outcome of adopting both decentralized control and open method will enhance the capability of functionality of the system from fixed to reconfigurable system[18]. The available
fieldbus in the market has provided essential features in order to implement both DCS (Distributed Control Systems) SCADA (Supervisory Control and Data Acquisition) and architectures [19]. A distributed control system (DCS) refers to a control system usually of a manufacturing system, process or any kind of dynamic system, in which the controller elements are not central in location (like the brain) but are distributed throughout the system with each component sub-system controlled by one or more controllers [20]. In modern industrial automation, the concept of DCS has been upgraded to the next level where the application of software inside the DCS system becomes a vital component. SIEMENS for example, has introduced flexible, scalable, powerful and innovative distributed control system which is SIMATIC PCS 7. Figure 3 shows example of SIMATIC PCS 7 components integrated in field bus plant network. In this network, there are several components that have been introduced which are automation station, operation station, engineering station, terminal bus (Ethernet – TCP/IP protocol), plant bus (PROFIBUS), and field bus (PROFIBUS DP/PA) [21]. Devices connected to field bus are ‘smart’. They deliver information about their health as well as the quality of the measured value [21]. The information of conventional 4-20mA analog communication is limited to control information only with insufficient management information. Nestlé Company for example, had adapted this powerful technology into their food processing automation system. The factory produces baby and toddler food for all of Europe. Up to 1000 jars and bottles are filled per minute on four production lines, which must conform to the highest product quality and safety standards. In order to meet these requirements and to ensure optimum efficiency of resources and maximum availability in the future, Nestlé had preferred SIMATIC PCS 7 systems into their food automation. The results were first class product quality, optimum efficiency of resources, and maximum availability [21].

**Figure 3.** SIMATIC PCS 7 integration in plant network [21]

4.0 Food Safety Applications
The demand for safe and high quality food have led to innovation and novel approaches in food processing and packaging industry [22]. In order to comply with certain standard, for instance Food Safety and Quality Division, Ministry of Health Malaysia (FSQD) has imposed specific requirements on the food product to ensure the safety of food for Malaysian citizen.

Since food safety has become vigorously important in the industry, it has been compulsory to have implemented the automated in-line food inspection system [6]. The presence of contaminants such as metal, glass, bone, rubber etc must be inspected and eliminated. To accomplish this, non-destructive
methods are chosen. The capability of non-destructive testing (NDT) to evaluate the food safety without compromising the quality becomes key element of its implementation. There are analysis of the effects of the drying process on the quality of food and propose the model to predict the changes in the biological and physical properties of the product through X-ray inspection [23]. Furthermore, X-ray technology also embeds artificial neural network methods and tools that provide sophisticated shape recognition functionality. The benefits of online X-ray system are the compatibility to changes in conveyor speeds, HMI (Human Machine Interface) compatibility, and system diagnostics. Besides, hyperspectral imaging is another excellent example of in-line inspection method. It is believed to increases the quality and the safety of the food products as well as improves productivity and throughput. Hyperspectral imaging offer the additional benefit of analysing the chemical composition of products hence increase production yields. By adopting this method into food processing and packaging industry, food products can be examined for disease conditions, ripeness, tenderness, grading, or contamination [24]. At the same time, machine vision application is become popular in the food industry. In this respect, the dual-band spectral imaging systems take place. The system has two-port camera system that comprise of two identical monochrome CCD cameras, and optical system and two narrow bandpass filters. The system is good in inspecting and testing off-the-shelf food products.

Traceability of food implies the ability to trace and follow a food, feed, or a food-producing animal or substance intended to be, or expected to be, incorporated into a food or feed, through all stages of production, processing, and distribution. The importance of traceability has grown due to the consumers increasing attention to food safety and food quality, and due to the increasing complexity of food supply chains [25]. A food processing and packaging industry must keep track of products, including the families of lots of production and distribution. This is crucial in order to react quickly to recall food products when a problem is reported. A track-and-trace system includes a data input system, software that includes a historian and analysis tools, and visualization and reporting [26]. Data input ranges from manual to such automatic tools as bar code and radio frequency identification (RFID).

5.0 Conclusion
As the food processing and packaging industry continues to remain competitive in an ever expanding global market, the need for technological advances that lead to increasing productivity, better product quality with enhanced safety assurance, and all at lower and lower cost, advances in automation and intelligent on-line control will inevitably continue at a rapid pace. In future, this industry is likely to transform conventional method to fully integrated and advanced manufacturing systems to further increase productivity without compromise the safety and hygienic issues. In this paper, the author have looked into the state of the art in food processing and packaging industry in terms of (i) packaging and materials, (ii) automation, control and fieldbus technology, and (iii) food safety technology. There is a need for a comprehensive research on overall food processing and packaging systems without neglecting the core element of any industry which is production management principle. Thus, food processing and packaging industry can benefit from the current findings in this area.

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