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Robotics: An emerging technology in dairy and food industry: Review

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Abstract
Technological advancement is gradually finding applications in the agricultural and food products, in response to one of the greatest challenges i.e. meeting the need of the growing population. Efforts are being geared up towards the replacement of human operator with automated systems. Presently, the technology is becoming more affordable and intelligent. It may be feasible to automate many of the complex and repetitive tasks that are carried out in the dairy and food industry through robotics. The field of robotics is both interdisciplinary and multidisciplinary as robots are amazingly complex systems comprising of mechanical, electrical and electronics hardware and software. Dairy and food industry has been lagging behind other industrial sectors in implementing robots, as dairy and food products by virtue of their nature differ significantly in consistency and shape. The dairy and food industry is now highly automated, from the raw material production to the processing and manufacture of products. The implementation of automation in the dairy and food sector offers great potential for improved safety, quality and profitability by optimizing process monitoring and control. However, there is a broad range of potential applications for robotics in dairy and food industries are grading of food products, pick and place operations, packaging and palletizing, meat processing, fruit and vegetable, milk and milk product, production and processing

Keywords: Robot, Robotics, Automation, Dairy

1. Introduction
Automation technology is changing the way the milk is produced and processed. The benefits are far-reaching: improved profitability, milk quality, lifestyle including animal welfare. Automation means every action that is needed to control a process at optimum efficiency as controlled by a system that operates using instructions that have been programmed into it. Automated systems in most cases are faster and more precise (Narendra *et al*., 2010) [32]. Some difficulties encountered in automation are lack of suitable sensors, low profit margins, use of batch/continuous operations and installation of equipment that is not integrated into the whole process.

The applications of robotics and automation have been successfully achieved in a wide range of manufactured industries dealing with well -defined processes and products (Hurd *et al*., 2005) [19]. However there are particular research challenges associated with the use of robots in the food industries (Peters, 2010) [34]. The first is that the objects being handled are variable in size, shape, weight and position, so that some form of intelligent sensing is required. The second is that the objects to be handled are often delicate and covered with either slippery or viscous substances, and so the end effect or must be carefully designed if it is to handle the objects at high speed with secure lifting and without bruising. The third is the concern for hygiene, quality and consumer safety. The hygiene issue is becoming increasingly important for human health. But all the three challenges have been accepted by modern robots.

In the dairy and food industry most systems are also isolated, batch type operations that target a specific task. For automation to be successful, it must be integrated into the overall manufacturing system design and provide on-line, continuous control capability. However, the trend is now changing rapidly as more and more dairy operations are being automated. India's first automated dairy plant with handling capacity of 1,000,000 LPD has been established at Gandhinagar near Ahmedabad in Western India.

Dairy and food processing industries is highly labour-intensive, with sometimes labour costs at anything up to 50% of the product cost. Improving productivity and reducing labour costs will therefore have a significant impact on profitability.

Much of the manual work in dairy industry requires rapid, repetitive, and monotonous movement and, consequently, low levels of motivation among workers. This leads to poor quality control and a high incidence of industrial accidents. Automating repetitive tasks will improve quality control and efficiency and reduce the high level of accidents. Today, the increasing technological development and sophistication of modern societies impose new quality and safety standards to the food producers. Consumers demand more and more information about the products. They are always demonstrating clear preferences for well-informed high-quality products. To assure the quality and safety of food products, automation can play a key role.

During milk and milk product processing, mostly fluid is transferred from one place to another through pumps, but still there are various operations where some form of solids has to be transferred repetitively. In dairy industry too, there is need for some movement of materials in hazardous atmosphere (as in ice store at -23 °C & in ice-cream hardening room at -30 °C). At this place, use of robot would be a good alternative. It can be expected that future dairies would be 'smart dairies' employing such robots capable of processing and handling milk and milk products most economically with a through control on quality too.

2. Reasons for automating processes

The purpose of automation is to increase process efficiency, safety, productivity and product quality. This is generally achieved by means of a control system that has been 'programmed' with a set of instructions. Followings are the reasons for automating industrial processes.

- Need to reduce direct labour
- Can't get people to do the job
- Need to increase quality
- Difficult to do the job manually
- Need to increase production
- Difficult to meet specifications consistently
- Need to provide flexibility in processes
- Hazardous to personnel

2.1 Basic considerations on the automation

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. Some industry like dairy lends them readily to automatic processing because the raw material (milk) has to 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 (Judal and Bhadania, 2015) [20].

3. Robot

Robot, from the Czechoslovakian word, "robota" meaning forced labour. A robot can be defined as a programmable, self-controlled device consisting of electronic, electrical, or mechanical units. More generally, it is a machine that functions in place of a living agent. According to British Robot Association, "An industrial robot is a reprogrammable device designed both to manipulate and/or transport parts, tools, or specified manufacturing implements through variable programmed motions for the performance of specific manufacturing tasks." The International Standards Organization (ISO) defines a robot as, "An automatically controlled, re-programmable, multi-purpose, manipulative machine with several degrees of freedom, which may be either fixed in place or mobile for use in industrial automation applications." Robots are especially desirable for certain work functions because, unlike humans, they never get tired; they can work in physical conditions that are uncomfortable or even dangerous; they can operate in airless conditions; they do not get bored by repetition; and they cannot be distracted from the task at hand. The robot is powerful, reliable and can be used in hot temperature area where a human after working for so long can become sick and exhausted (Agrawal *et al*., 2010; Nayik *et al*., 2015) [2, 33].

3.1 Robotics

Robotics is the branch of technology that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, sensory feedback, and information processing. These technologies deal with automated machines that can take the place of humans in dangerous environments or manufacturing processes, or resemble humans in appearance, behaviour, and/or cognition.

The function of different component are, Processor: It is brain of the robot, calculates the motions and the velocity of the robot's joints, etc. Sensors: To collect information about the internal state of the robot or to communicate with the outside environment. Software: Operating system, robotic software and the collection of routines. Rover or Manipulator: Main body of robot (Links, Joints, other structural element of the robot). Actuators: Muscles of the manipulators (servomotor, stepper motor, pneumatic and hydraulic cylinder). End Effecter: The part that is connected to the last joint hand of a manipulator Controller: Similar to cerebellum. It controls and coordinates the motion of the actuators (Massey *et al*., 2010) [31].

Table 1: Features and benefits of robotics.

Features	Benefits
Better process control	Easy to clean robot, minimum retention areas, connection protection
High reliability, high speed	Increased productivity
High dexterity, several mounting positions	Compact cell, less room required, simpler mechanical solution
Cleanliness	Better hygiene
Flexibility	Marketing innovative products and packaging
Vision and conveyor tracking	Product picked and controlled in process, in any position

(Anon., 1996)

3.2 Parts of a robot

Robots come in many shapes and sizes. Robots consist of a number of components that work together: the controller, the manipulator, end effectors, a power supply, and a means for programming (Schilling, 1990). The relationship among these five components is illustrated in the figure 1.

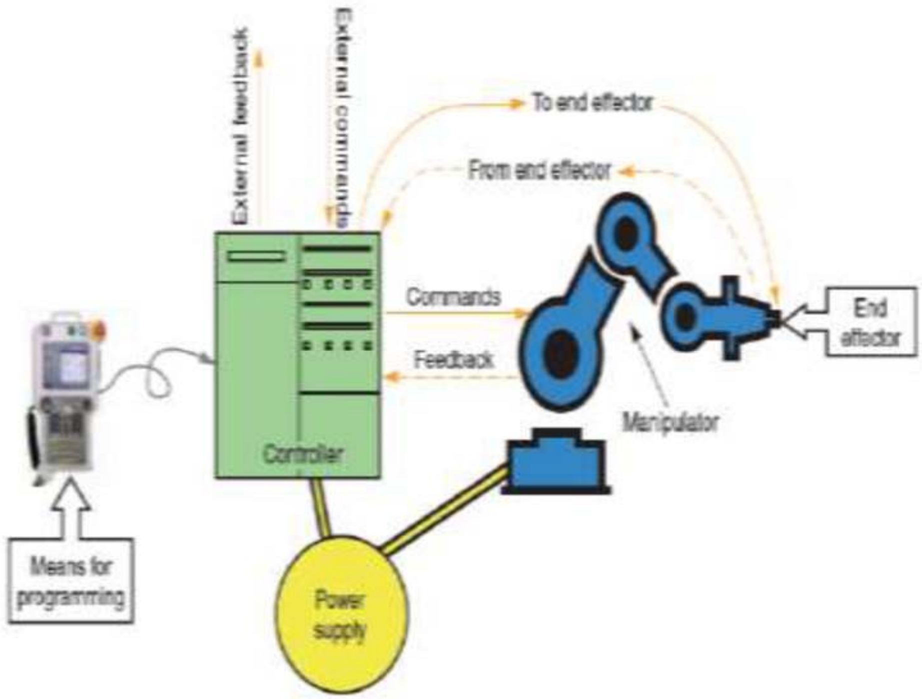

Fig 1: Parts of the robots

An actuator is a motor or valve that converts power into robot movement. This movement is initiated by a series of instructions, called a program, stored in the controller‘s memory. The manipulator consists of segments that may be joined and that move about, allowing the robot to do work. The manipulator is the arm of the robot which must move materials, parts, tools, or special devices through various motions to provide useful work. The end effector is the robot hand, or the end-of-arm tooling on the robot. It is a device attached to the wrist of the manipulator for the purpose of grasping, lifting, transporting, maneuvering, or performing operations on a work piece. The power supply provides the energy to drive the controller and actuators. It may convert AC voltage to the DC voltage required by the robot’s internal circuits, or it may be a pump or compressor providing hydraulic or pneumatic power. The three basic types of power supplies are electrical, hydraulic, and pneumatic. The means for programming is used to record movements into the robot’s memory. A robot may be programmed using any of several different methods. The teach pendant, also called a teach box or hand held programmer teaches a robot the movements required toper form a useful task. The operator uses a teach pendant to move the robot through the series of points that describe its desired path. The points are recorded by the controller for later use (Judal and Bhadania, 2015) [20].

3.3 History of Robot

- 1956 - George Devol applied for a patent for the first programmable robot, later named 'Unimate'
- 1961 - First Unimate robot installed at General Motors, used for die casting and spot welding
- 1986 - Honda starts work on its first humanoid, robot named 'E0' (later to become ASIMO)
- 1988 - SCAMP designed as the first robot pet with emotions
- 1995- Robot used in packaging and palletisation line
- 1997- Industrial Research Ltd. New Zealand, develop robot for sheep de-fleecing and cutting
- 1999- GTRI develop a robot for deboning of meat
- 1991 - First Helpmate mobile autonomous robot used in hospitals
- 1992 - Development of robot for picking of citrus fruit in Spain
- 2002 - iRobot introduces Roomba, a personal robotic vacuum cleaner.
- 2004 - Reed develop robot for harvesting of mushrooms
- 2006 - The world's first robotic rotary dairy was developed by Delaval
- 2010 - NASA and General Motors join forces to develop Robonaut-2, the new version of NASA's humanoid robot astronaut

3.4 Types of robot used in dairy and food industries

The recent developments in the food industry, different types of robots were put into operation for several purposes. The old model SCARA (selective compliance assembly robot arm) robots for pick and place, spider robots for high speed picking and placing of light weight objects are the recent examples of robots used in the industry. SCARA robots are one of the types of stationery robots also known as horizontal articulated arm robots, with motions same as human arm. Its reliability for fast and repeatable movements make it fit for packaging palletizing, loading and unloading purposes (Brumson, 2011) [8]. Delta robot is also known as Parallel Link Robots are the category of modern day robotics. Delta robots are designed for high-speed handling of lightweight products and offer lower maintenance due to the elimination of cable harnesses and absent of multiple axis. Parallel robots are deployed into many food processing steps. Again they offer high speed transfer food stuffs, primary (unpacked) or secondary (packaged) through manufacturer lines and a multitude of processes.

3.5 Specifications for a food sector robot

Varieties of robotic systems, developed for such sectors, are readily available from international companies, and are often offered as manufacturing solutions for the food industry. Any design should meet the guidelines for food-handling equipment (Lelieveld *et al*., 2007) [27] and be ideally of stainless-steel grade AISI-304 and construction with ingress protection rating to IP67, and all parts visible and accessible for inspection and manual cleaning. The standards of hygienic design required will depend on the application, being higher in processing poultry and fish products than in processing dry-food products, such as biscuits or bread. A general purpose robot, which could potentially be used to process any type of product, should meet the highest standards of hygienic design.

4. Application of robotic in Agricultural

4.1 Sowing, Weeding, Spraying, and Broad-Acre Harvesting

When the individual operations are considered, the technologies vary in their importance. For spraying, 0.5 m accuracy is usually sufficient. Here, however, demands of speed are at their most important, so there is a trade-off between a GPS with a once-per-second update with inertial assistance and the 5 Hz GPS that is becoming more common. For yield monitoring, where the harvested yield might be apportioned into 5msquares, GPS with 0.5m precision is also sufficient. When listing up, there is little or no visual reference in the field. Precision GPS and inertial sensors have a clear lead. However, when a good furrow has been formed, planting can employ a simple mechanical furrow follower, a ball or wheel trailed from an arm projecting in front of the tractor. When seedlings have emerged, machine vision offers great advantages over GPS guidance. While cultivating, any dynamic positional errors at the planting stage will be added to steering positional errors; the blades must be set further from the row if the risk of destroying plants is to be contained. Vision can track the wander in the planted rows so that only one level of errors will be involved. When a cotton crop is ready for harvesting, simple methods can again be used. Mechanical stem feelers are ideal for guiding the harvester precisely along the rows and these have been successfully field-tested by the National Center for Engineering in Agriculture (NCEA). For wheat, however, vision could still be supreme. The Illinois researchers have investigated visual ways of detecting the boundary of the previous cut. A simpler robot already in widespread use is the center-pivot irrigation device. These systems are self-propelled, irrigating an area of up to 600 acres per pass. Add-ons such as GPS, moisture monitors, and even imaging devices add sensory input for decision making. In this way, water and fertilizer may be applied to specific areas of the field at specific rates dependent on conditions (Edan and Rogozin, 2010) [15].

5. Application of Robotic in Food Processing industries

The food industry is a highly competitive manufacturing area, but with relatively little robotic involvement as compared to the automotive industry. This is due to the fact that food products are highly variable both in shape, sizes and structure which poses a major problem for the development of manipulators for its handling (Chua *et al*., 2003). So far, commercial application of robots in food industry is widely spread at the end of processing lines like packaging and palletizing. However there is a broad range of potential applications for robotics in food processing: in the grading of food products, pick and place application, packaging and palletizing, meat, dairy and baking lines to handle hot trays.

5.1 Grading of food products

The grading robot system made various effects like, labour substitution, objective grading operation without human subjective judgment, data accumulation for traceability and farming guidance to producer. Kondo *et al*. (1996) [25] developed a fruit harvesting robot for use in Japanese agriculture systems which commonly produce crops in greenhouses and in small fields. Reed *et al*. (2001) [37] developed an end-effect or for the delicate harvesting of mushrooms. A grading system using robots has been developed for use with deciduous fruits such as peaches, pears, and apples. System automatically picks fruit from containers and inspects all sides of the fruit (Kondo, 2003) [24].

5.2 Robotics in Fruit and Vegetable Processing Industry

The first automated grading facilities for fruit and vegetables became available more than 10 years ago. Robot technology has proved able to handle agricultural products delicately and with a high degree of precision, and to gather information to create a database of products every season. Since about ten years ago, packing robots and palletizing robots have been a frequent feature in fruit grading facilities, while grading robots (Kondo, 2003) [24], which collect round-shaped fruits and inspect them using a machine vision system, are now being introduced in some East Asian countries.

5.2.1 Picking of Fruit and Vegetables

Once we leave broad-acre crops, harvesting can require selection and sensing. Brute force tree shakers might be used for picking some citrus fruit, but hand-picking is still common. Intelligent picking has presented a challenge to many robotics researchers (Edan and Rogozin, 2010) [15]. Picking can sometimes take the form of a location or localization task, deriving a target position for the picking actuator. At other times there is an additional requirement to determine which of the fruit are ready for picking and which must be left to ripen. At present, the automation consists of no more than conveyor belts extending each side of a tractor while hand-pickers walk the field, choosing which to cut, be they broccoli, rock melons, or cauliflowers.

The gathering of macadamia nuts is performed by a manually steered vehicle with a bristle roller which gathers up the nuts from the ground. What brings it to the attention of robotics is a localization task associated with selecting for varietal strains. It is necessary to attribute each kernel to the correct tree, meaning that the absolute position must be measured. Cameras inspect the rollers just before the nuts are stripped, so that the pick-up location is known precisely with respect to the vehicle, but that leaves the task of locating the vehicle. GPS is unreliable under the tree canopy, so the system combines odometry with tree-trunk location using both sideways-looking visual streaming and radio frequency identification (RFID) tagging (Dunn and Willingsley, 2003) [14]

5.2.2 Automatic fruit harvesting method

A) Canopy Shaker

A canopy shaker was designed to clamp secondary limbs and to shake vertically. The shaker was extended into tree with a pantograph lift unit and shake always vertically. An excessive immature orange were removed during tests conducted by Summer. Two continuing canopy shakers were reported by Futch and Roka, one was self-propelled unit and another was tractor-drawn unit. These two units were used for juice processing plants. Manual workers were needed to collect the fruits after the harvest. Shaking frequency and stroke are important factors in the performance in this type of harvester and it requires more tests to determine the optimal values.

Fig 2: Canopy Shaker

B) Ultrasonic sensing

This Technique can be illustrated by an example of an eggplant harvesting robot. We designed a robot to harvest eggplants (Solanum melongena) trained on a V-shaped frame. The robot includes sensors (CCD camera and ultrasonic distance sensor), a manipulator with seven degrees of freedom, an end-effector, a traveling carriage. The sensors are attached to the end-effector (Fig. 3). The robot runs between rows and scans images of the eggplants on both sides through a combination of travel and manipulator control in the order.

The visual sensor has two functions: global and local sensing. When the global sensor detects an eggplant, the end-effector approaches the fruit and stops at 160 to 250 mm in front of it. At this point the fruit length is estimated by the visual sensor and the ultrasonic distance sensor. If the fruit is of marketable size (>120 mm long), scissors hold and cut the peduncle. Finally the robot transfers the fruit to a container.

Experiments were conducted in a greenhouse. Plants of cultivar 'Senryo-2' were planted 400 mm apart in a 4-m row. The numbers of total and marketable-sized fruits were counted beforehand, and then after harvest we calculated the successful harvesting rate, undersized-fruit harvesting rate, harvesting time per fruit, and total harvesting time. This study shows that the robotic system can harvest marketable-sized eggplants without damage, although further development is necessary.

Fig 3: The end-effector of the eggplant-harvesting robot

C) Machine vision technique by shape

Machine vision technique by shape can be most suitably used for citrus fruits. Many different researchers such as Hannan *et al*., (1987) [17] have incorporated shape into their fruit detection algorithms. Citrus in general tends to have a round shape, whereas tree branches and leaves tend to have more straight and pointed shapes. Looking for round objects can be simple way to detect fruit, but as with colour detection, shape detection can also have several problems. The main problem is occlusion. Fig 4 shows images of the two main types of occlusion when observing oranges. Figure 4 (a) is an example of leaf occlusion. Leaf occlusion complicates fruit detection by disrupting the shape of the fruit and minimizing the amount of the fruits colour that is visible. Figure 4 (b) is an example of fruit occlusion caused by clustering of several fruits. Fruit occlusion also disrupts the shape of the fruit in much the same way as leaf occlusion. Fruit occlusion can cause multiple fruit to appear as a single large fruit, unlike leaf occlusion where there is distinct contrast in colour between the leaf and the fruit.

Fig 4: Problems: (a) Leaf and (b) Fruit Clustering

Another situation that is important is that there are certain varieties of orange trees that grow both the current season's harvestable fruit as well as next year's immature fruit. The result is that the tree will have both orange and green colored oranges at the same time. A successful citrus detection strategy will require the understanding and full exploitation of both the colour and shape of the fruit. Image processing will be needed to determine how to best detect the color in a variety of lighting conditions, while at the same time being able to compensate for the differences in the fruits natural colour. Image processing will also need to detect fruit when leaves or branches occlude it, or when it is clustered with other fruit. A fruit detection algorithm that is economically feasible for mass harvesting will require a combination of both the colour and shape properties of citrus (Shigehiko *et al*., 1993) [39].

6. Online Egg Sorting

Online poultry inspection by a multi-camera system can be employed to accurately detect and identify carcasses unfit for human consumption (Chen *et al*., 2002) [11]. By automating this process, the level of accuracy in identifying defective eggs increases; and the rate of sorting is higher. The 1.4 Megapixel cameras are positioned in such a fashion as to capture images from every angle as the eggs roll down a conveyor belt. The cameras monitor the quality of eggs passing through the system and the images are analysed digitally, with complex algorithms identifying any hairline cracks or detritus on the egg's surface. Commercial Machine Vision Sorter Virtually all electronic classifiers currently available have a series of elements in common. Basically, they all consist of a feeding system that individualizes the fruit, a transport system, an inspection system formed by sensors that measure parameters related to product quality, a system that processes these measurements and makes decisions on quality, a system for synchronization, a system for separating the production categories, and an user interface and a software that manage the whole machine.

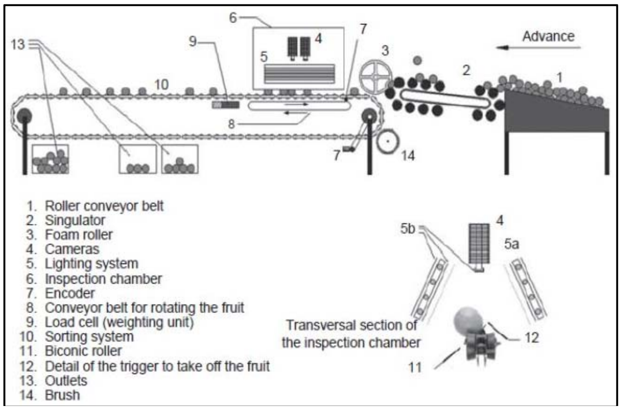

Fig 5: Commercial Machine Vision Sorter

7. Automatic Process Monitoring

Application of machine vision has been reported for controlling drying process of sliced apple. The vigilance of a drying process was provided due to online image analysis and correlation of image attributes (area, colour and texture) with physical parameters of drying (moisture and quality). A relationship between area shrinkage and moisture content was used for online estimation of actual moisture content. A relationship between color intensity and quality was used for online estimation of quality degradation during drying of ginseng roots (Martynenko, 2006) [30]. Strickland (2000) [40] reported the use of digital imaging technology for the automatic monitoring of dry sugar granules and powders. This system provides particle size data to production line operators for process control and product quality improvement.

8. Livestock Inspection

As with produce, grading and classification of livestock carcasses is becoming more commonplace. Poultry (Big Dutchman, 2005) [5] is one application where the advances in image sensors and filters for particular spectra combine to provide automatic detection of disease and contaminants in a poultry processing line.

An application involving individual recognition of production animals is in full commercial use by Big Dutchman. In this circumstance, pigs are tagged with unique radiofrequency identification (RFID) ear tags. As each animal enters a feeding bay, the tag is read and an appropriate ration of food is delivered. This allows individualized diets and medication delivery to improve the bottom-line cost/benefit for pork producers.

Another novel method of identifying and controlling animals is being developed in Southern Queens- land (Vaughan *et al*., 1998) [43]. Using machine vision, each animal proceeding along a laneway towards water is classified at the species level. An automated gate then either allows or denies access to the watering point. The same technology can be used to remotely draft production animals based on a condition score into several different categories.

9. Meat processing

The potential applications of robots in the meat processing industry have been investigated for several years. The main aim of using an industrial robot is to reduce production costs and occupational injuries while improving process efficiency and hygiene. The strength of robotics, particularly in boning rooms where labour costs are inherently high, is in their ability to perform the required repetitive tasks more efficiently and consistently than is currently possible (Food Science Australia). Georgia Tech researchers have developed a system that uses advanced imaging technology and a robotic cutting arm to automatically debone chicken and other poultry products. This robotic system is used for the intelligent cutting and deboning of a chicken, as it prepares to slice through the shoulder joint of a chicken, cutting close to the bone to maximize breast meat yield and ensuring food safety by avoiding creation of bone chips (Calderone, 2013) [10]. In beef production the first use of robotic equipment was in splitting complete carcass into carcass sides. The Meat Industry Research Institute of New Zealand (MIRINZ) has in particular been very active in automation of sheep and lamb slaughtering. The Danish company SFK-Danfotech has, in cooperation with the Danish Meat Research Institute (DMRI), has developed a series of dedicated robots for automation of pig slaughter line processes (Madsen and Nielsen, 2002). After the meat is cut and deboned, it is then sliced, packaged, and shipped to the customer. Vision-guided robots are speeding up these practices to make certain that the pieces are accurately portioned and cut, while packaging equipment is incorporating volumetric scanning systems.

9.1 Robots in beef processing

Beef production is the least automated of the large carcass types. The first area where robotic equipment exists is that for splitting of a complete carcass into carcass sides. The equipment for this is produced by a number of manufacturers.

An ambitious beef sectioning system is proposed by the Texas beef group in a patent issued in 1993 (Brien and Malloy, 1993) [6]. A chilled eviscerated carcass is mounted horizontally on an automatic guided vehicle and appraised using X-rays, 3D machine vision and ultra-sonic sensing. The results of the inspection are used to generate cutting paths to enable the carcass to be cut into optimal primal sections. A robot is used to effect this separation with high pressure water, abrasive and air jets. Flesh is cut with the water jet while the air jets keep the severed meat clear of the cutting area. The abrasive jet is invoked when cuts are to be made through bone. This is a particularly high-tech proposal in a patent and it is not known whether the ideas are being put into a commercial system.

Research into automation of beef boning has taken place in Australia (Clarke *et al*., 1988) [13] and UK (Purnell *et al*., 1990, 1993). Both systems utilise force feedback systems to guide a reciprocating blades cutter along the surface of the bone. The UK system, developed at the University of Bristol, also involved machine vision and the play-back of experience to improve the cutting process. Although laboratory trials suggested the success of these techniques, cutting speeds were too low to be economic and no meat industry equipment was constructed.

9.2 Robots in pork processing

Automated cutting systems for pork exist that separate a half carcass into fore, middle and hind sections. The process was developed in conjunction with DMRI and the equipment is produced by Attec in Denmark and Itec in Germany (Folkman, 1995). Carcasses hanging on a standard gambrel are pulled across a conveyer belt and the hind feet cut off.

This releases them from the gambrel onto the conveyor. At a second station each carcass side is moved against datum surfaces and the length between the pubic bone and the fore leg is measured. This measurement is used to position circular saws further down the line to anatomically derived cut positions for that carcass side.

Fully automatic systems for collecting and grading information and carcass stamping have been developed in Denmark and in Holland. Since 1989 all Danish export pork carcasses have been classified with the fully automatic Pig Carcass Classification Centre developed at the DMRI. Work on pork evisceration by robot has been carried out in the mid-80s under a European Union funded programme (BE4152, 1991). This work has been continued by the DMRI and industrial companies working towards an automated pork evisceration production system.

10. Robots in freezers and ovens: -

When handling food, robots are located in freezers or near ovens, while these environments generally do not harm robots, some defence must be made to ensure the robots operate efficiently. The robots based inside freezers for palletizing operations preclude undesirable frosty condensation from building up on ice cream packages (Suganya *et al*., 2011) [42].

11. Robotics in dairy industry

The use of robotics in the food industry has increased over recent years, particularly in the field of processing and packaging systems. However, the industry has not taken to the technology with the same enthusiasm as the automotive and other industries. Now that the technology is becoming more affordable and the systems more intelligent, it may be feasible to automate many of the complex and repetitive tasks that are carried out in the food industry. The opportunity still exists to deliver significant benefits in terms of increased food shelf life, cost reductions and flexibility (Wallin, 1997).

Dairy industry has been lagging behind other industrial sectors in implementing robots, as dairy food products by virtue of their nature differ significantly in consistency and shape. However, there is a broad range of potential applications for robotics in dairy industries. Automatic milking systems (AMS) or milking robots are one of the most successful and important application of robotics in the dairy industry. The commercial application of robots in dairy industry is also widely spread at the end of processing lines like packaging and palletizing.

11. Robotic milking

Milking cows by machine, to replace the practice of milking by hand, has been known for more than century. Automatic milking systems (AMS) or milking robots are one of the most successful and important application of robotics in the dairy industry. Automatic Milking Systems also referred to as robotic milkers, were developed in Europe and became available there in 1992. This technology was introduced to the US in 2000.

Robotic milking is a voluntary milking system, which allows the cow to set her own milking schedule. following an initial training period, cows are milked with limited human interaction. Each cow on a robotic milking platform is fitted with an electronic tag which allows the robot to identify her. When a cow enters her ID tag is read and she receives a feed reward customized to her level of production, the robot then cleans her teats, attaches the milk cups, and begins the milking processes when milking is complete, the cups disconnect as each quarter finishes milking and she exits (Butler *et al*., 2012; Brogardh, 2007; Higgs & Vanderslice, 1987) [9, 7, 18]. In this type of advanced system milking occurs throughout the day and night.

The world's first commercial robotic milking rotary has been unveiled by Swedish dairy equipment company DeLaval at a pilot farm at Quamby Brook, Tasmania, Australia. Featuring five robots, the rotary has a capacity to milk up to 90 cows per hour, enabling the robots to reach the cow from the side. With the use of laser technology, the robots focus a red light to determine the location of the cow's teats, clean them and attach the cups. The first two robots clean and prepare the teats for milking, the second two attach the cups to the teats, and the last robot sprays the teats to disinfect them before the cows reaches the platform (Khodabandehlco, 1994; Legg, 1993) [23, 26]. Once the milking is done, robotic liquid filling and finishing systems get the product ready for market. These robots handle many types of bottles, vials, bags, and pouches with precision filling from micro liter to multi liter. The containers, once filled, can be closed using a screw cap, stopper, or crimp. They accommodate a variety of products; and deal with fill volumes, dispensing profiles, containers and closure types, making them ideal for clinical trials, full scale production and contract manufacturing (Judal & Bhadania, 2015) [20].

11. Advantages of robotic milking

Milking by using robots has various advantages like:

- Economic benefit: Labour flexibility and not needing to manage hired labour were the biggest advantages reported by current users of robotic milkers.
- Increased milking frequency: Milking frequency may increase to three times per day, however typically 2.5 times per day is achieved. This may result in less stress on the udder and increased comfort for the cow, as on average less milk is stored. Higher frequency milking increases milk yield per cow.
- Management benefit: Management of the herd can be made more efficient. For a farmer who's never managed his cows properly the robot computer will force him to do so. It tells him about blood in the milk, conductivity, and yield per quarter.
- Cow health and welfare benefits: Producer reported an improvement in cow health and a reduction in instances of mastitis following the transition to robotic milking. This was attributed to less stress on the cows and to have better access to information on their cows. For example, benefits resulting from quarter-by quarter milking, which can help to reduce udder infections (Nayik *et al*., 2015) [33]

12. Robotics in packaging

A large majority of the estimated 76 million cases of food borne illness that occur annually in the United States are a direct result of the contamination of food by food handlers in food processing facilities. Transient food borne microbes can be introduced from infected humans who handle the food, or by cross contamination from some other raw food product that a human recently handled. Food contamination can also occur when human hair, skin, nails, or other materials are found in food. Transient organisms are of particular concern because they are readily transmitted by hands unless removed by the mechanical friction of washing with soap and water, or destroyed by the use of an antiseptic solution. Transient organisms can be considered skin contaminants that are acquired from environmental sources and become attached to the outer epidermal skin layer. Robotics and automation in food processing and packaging are one of the many possible paths available to reduce the introduction of these bacteria (Nayik *et al*., 2015) [33].

The growth in products packaged for the market, the increasingly strict hygiene regulations, the need to reduce risks at work, cut costs, and control product quality are all calling for the development of technologies that enable robots to be used for these tasks. In fact, robotics has a great opportunity in this industry and in particular for Pick & Place operations (Wilson, 2010). Examples of robots for this purpose include ABB IRB-660 and IRB-360. The former is a serial robot used for high demanding payload transfer while the latter is based on PKM mechanism (Wilson, 2010) and is designed for high capacity collating, picking and placing of products onto trays, cartons or feeding of other machinery. Many food companies and packaging machinery manufacturers have successfully applied robots in a wide variety of processes in the dairy, meat, baking, confection, frozen, snack and even in beverage industries (Purnell, 1998) [36].

Beyond handling unwrapped products, robotic packaging systems have successfully been implemented in: Placing products into the in feed buckets of side-loading cartons. Placing products directly into top-loading cartons. Filling the product pockets in a form, fill and seal machine. Creating product arrays or stacks at the in feed to a bagging operation. Loading and unloading a retort process. Descrambling bottles from bulk for the in-feed of filling, capping and labelling machines. Packing products into reusable or single-use trays. Unloading various types of baked goods from pans. Unloading and case-packing single-serve portion packages from filling machines. Palletizing and depalletizing beverages, cases, bags, pails, totes, bulk containers, cans, bundles, etc. The history of robots and other automation technologies in the food industry goes back decades, mainly involved in palletizing tasks; so called downstream applications. But as food industry giants continue converging and demand continues unabated from large warehouse outlets, grocery chains and consumers for fresh products quickly, newly emerging configurations in robots with related automation technologies, including vision systems and processing software, is seeing robot applications move upstream for picking and packing (Adl *et al.*, 1991).

The commercial application of robots in food industry is widely spread at the end of processing lines like packaging and palletizing. However, there is a broad range of potential applications for robotics in food processing: in the meat industry, robots are used in slaughtering, deboning, cutting, sorting and packaging applications. Robots can also be used for picking and placing items such as cookies, hamburgers, chocolate pralines, croissants, chicken fillets or pan cakes into primary packing. Additionally, robots are already used in baking lines to handle hot trays. Reducing demands on labour can be a big plus point for robots especially when labour is expensive and in high demand. Moreover, robots minimize the human workers direct contact with the products.

In the early 1990's, the first applications in direct food handling in the bakery industry was seen. These robots were performing simple pick and place operations at a reasonable rate of 55-80 cycles per minute. And vision guidance technology now had the capacity and reliability to provide pick locations to multiple robots operating at these high repetitive rates. Probably the most significant factor for robotics and vision technology was the continuous reduction of cost per unit of performance of these components (Peters, 2010) [34]. One of the most significant "soft" justifications was worker related injuries such as repetitive motion injuries being identified in high volume packaging applications. This new food processing and packaging market, now identified, needed additional technology adapted to the specific requirements:

- Performance to exceed the labour payback hurdle
- Further improvements addressing sanitary standards

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- Placing products into the infeed buckets of side-loading cartoners
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- Filling the product pockets in a form, fill and seal machine
- Creating product arrays or stacks at the in feed to a bagging operation
- Loading and unloading a retort process
- Descrambling bottles from bulk for the infeed of filling, capping and labelling machines
- Packing products into reusable or single-use trays
- Unloading various types of baked goods from pans
- Unloading and case packing single-serve portion packages from filling machines
- Palletizing and depalletizing beverages, cases, bags, pails, totes, bulk containers, cans, bundles, etc.

In the dairy industry, robots are used in cheese packaging, cheese slicing, and curd slicing etc. In cheese production, robots stir curds, transfer cheese moulds, and turn, cut, portion, package and palletize the cheeses. Integrated sensors and measuring systems enable the simple implementation of complex processes. Blocks of cheese arrive on wooden planks at the robot picking area. The special gripper allows the cheese blocks to be picked and placed onto a conveyor for further processing (Kempthome, 1995). The picking and packing robots are shown in figure 6.

Fig 6: Picking and Packing robot

13. Increased yields and reduced wastage

The food processing industry combines an extensive diversity of products, packaging types and handling variations than almost any other industrial sector. There is a wide range of potential applications for robotics in food processing from the meat industry, where robots are used for cutting, sorting and packaging applications (Peters, 2010) [34]. Working in a freezer or refrigerated storage boxes is not conducive to humans, but robots can work in such places without ever needing a break. Cutting and trimming carcasses can be very dangerous work, where a moment of distraction could cause serious injury; but robots can wield heavy and sharp knives with absolute precision. Human workers can taint foods with pathogens, whereas robots are considerably more sanitized, as they can be washed with high pressure water and solvents. Robots do not sneeze or get colds, reducing the propagation of germs and bacteria. Standard robots have been in use for many years in many industries.

However, the meat sector has been reluctant to introduce standard industrial robots for a number of reasons including:

- The harshness of the environment in the meat industry
- The speed, reliability and cost of the robots.
- The complexity of the processes involving handling biological materials

The use of automatic equipment has therefore been the dominant feature for the meat sector (Brien and Malloy, 1993) [6]. During the last few years' industrial robots with names such as 'Clean Room Robot', 'Envirobot' and 'Shiny Robot' have been introduced to the meat industry. Industrial Research Ltd., New Zealand, has marketing the Envirobot for handling organic products in harsh environments such as the food industry.

The Envirobot is made of stainless steel and resists harsh cleaning materials and the corrosive chilled environment in slaughterhouses (Stone and Brett, 1994) [41]. Both from a working environment, a cost and a hygiene point of view, the evisceration process is an obvious candidate for automation. This has been done successfully by the DMRI in co-operation with the Danish company SFK-Danfotech. The automatic evisceration equipment is capable of handling 360 carcasses per hour including the necessary cleaning and disinfection. The pluck set and the intestinal tract are removed together by the robot, allowing separation to be done manually outside the carcass, thus improving hygiene compared with existing manual methods. The equipment also eliminates the heavy work of lifting the intestinal tract and the pluck set.

Robotic system is used for the intelligent cutting and deboning of a chicken, as it prepares to slice through the shoulder joint of a chicken, cutting close to the bone to maximize breast meat yield and ensuring food safety by avoiding creation of bone chips (Brien and Malloy, 1993) [6].

14. Limitations

Robotic systems and robots are limited to their functions and only the programmers really known what those functions are, unless artificial intelligence is highly sophisticated, robots may not respond properly in times of an emergency of when some unexpected variance. Since artificial intelligence is becoming more sophisticated and robots will be entering more households, there may be important negative effects on the human family system (Suganya *et al*., 2011) [42].

15. Future challenges and opportunities of R & D in robotics

A very recent trend is to apply the concept of Cyber Physical System (CPS) in dairy and food industry. Bridging the physical world with the virtual world, CPS is a recent multi-disciplinary research domain based on the concept of Internet of Thing (IoT) that finds potential to streamline end-to-end supply chain in food sector. CPS can play its role to achieve the highest level of certainty in food safety (Khan *et al*., 2014) [22]. Food industry together with agricultural sector is listed as one of the priorities where CPS is anticipated to have significant impact in future. In the long term milestone, the whole production and supply chain will witness communication of smart food labels so as to give in-depth insight of where exactly the food is coming from (Piramuthu and Zhou, 2016) [35]. Also, future CPS in emerging sectors like dairy and food industry will be beneficiated by cloud robotics.

16. Conclusion

Robots have potential to change our economy, health, living and the world we live in. It is the technology for the future and with a future. The current research goals and trends indicate that the industrial robots of the future will be more robust, accurate, flexible, and mobile with more than one arm and will have many more capabilities. The robots will be human friendly and intelligent, capable of responding to voice commands and will be easy to program. Image processing is recognized as being the core of machine vision with the development of more efficient algorithms assisting in the greater implementation of this technique. Robotics has the potential to become next frontier in the dairy and food industries. Manual handling of foods is not going to end soon, but still the acceptance of automation and robotics in the industry is increasing. Even though robots bring with them so many advantages like safety, consistency and efficiency, the challenges that lies before food robotics are the high costs involved and the requirement of skilled engineers. Hence there is immense potential of research in robotics for those specialized in automation, while educational institutions have an equally important role in imparting the advanced knowledge to keep the food. The use of robots shall not come by choice but dairy and food industry has to adopt this modern technique to remain cost efficient.

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