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Robotics in food processing industries: A review

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Abstract
The application of robotics in the modern food processing sector has be increased in recent years, due to its numerous applications. This study provides a comprehensive assessment of robotics applications in the food processing industry, focusing on a relatively new application area. Robots have the ability to alter food processing and handling, food serving procedures, and palletizing and packing. As a result, factors such as robot dynamics, economical efficiency, kinematics, human-robot interaction, hygiene, safety and protection, operation and maintenance are crucial, and are covered in this review. According to the analysis, the food serving sector is a new prospective field with several research prospects due to the integration of breakthroughs from various technology disciplines. It is expected that greater distribution of 'food-robo' research achievements will promote more cooperation within the research community and contribute to subsequent developments.

Keywords: Robotics, food processing industry, kinematics, palletizing and packing

Introduction
Over the last two decades, advances in various technological domains have transformed 'fictional' robots into reality. Robotics is a subset of industrial automation. The pressing need for increased productivity has necessitated the deployment of robots to automate tasks. Robots are now viewed as an essential component of many industries (Iqbal *et al*., 2017) [6]. Robot is derived from the Czechoslovakian term "robota," which means "forced labour." A robot is a programmable, self-controlling device made out of electronic, electrical, or mechanical parts. In general, it is a machine that performs the functions of a live agent. "An industrial robot is a reprogrammable device designed both to operate and/or move components, tools, or defined manufacturing implements through changeable programmed motions for the completion of certain production activities," according to the British Robot Association. A robot, according to the International Standards Organization (ISO), is "an automatically controlled, re-programmable, multi-purpose, manipulating machine with numerous degrees of freedom, which may be either fixed in place or mobile for use in industrial automation applications." Robots are particularly desirable for certain job functions because, unlike humans, they never tire; they can work in physically uncomfortable or even dangerous conditions; they can operate in airless environments; they are not bored by repetition; and they cannot be distracted from the task at hand. The robot is powerful and dependable, and it can be utilized in hot environments where a human would feel ill and fatigued after working for so long (Ahmad Nayik, 2015) [1]. The robotics industry is growing at a compound annual growth rate of 17%, and global robotics spending is expected to reach $135 billion by 2019. The total Global Food Robotics Market is estimated to reach USD 3,795.4 Million by 2028. The Market valued a revenue of USD 1,842.5 Million in the year 2021, and is anticipated to grow at a Compound Annual Growth Rate (CAGR) of 12.80%. The two largest manufacturing sectors that buy robots are automotive and electronics, both of which mass-produce items with numerous separate components that must be assembled precisely. Other industries, such as healthcare, are rapidly incorporating robots into their operations. The food industry is one industry where robots are not widely used (Chrisandina, 2018) [4].

When compared to the work done by a human chain, manufacturers in the food industry saw a +25 percent increase in productivity after implementing robotics. However, the work rate of execution varies by food sector. In reality, it is determined by several factors such as the level of automation used, the number of robots deployed, and product variation due to changes in customer demand. Previously, the use of robots in the food industry was limited to food packaging and palletizing in dairy, beverages, chocolates, and food tins. In comparison to traditional processes, food manufacturing and processing plants are now using cost-effective automation solutions to increase production quantity.

Because reliance on manual labour is now considered a traditional concept, more emphasis is placed on robotized handling/manufacturing installation. Picking, placing, packaging, and palletizing applications are common examples. The majority of the food processing industry demands product variation without requiring changes to the processing line or tinkering with hardware. Recent trends indicate that investment in robotic automation is critical for this industry to address competitive challenges by protecting the business's future and reducing the impact on environmental degradation. As a result, businesses look for expert robotic solutions that are tailored to the needs of the processing line (Iqbal *et al*., 2017) [6].

When a process is automated, it can run even without human intervention. In fact, most automated systems can perform their functions with greater accuracy and precision, and in less time, than humans. Robotics and automation have been successfully applied in a wide range of manufactured industries dealing with well-defined processes and products. However, there are specific research challenges associated with the use of robots in the food industries. The first is that the objects being handled vary in size, shape, weight, and position, necessitating the use of intelligent sensing. The second reason is that the things to be handled are frequently delicate and covered with either slippery or sticky substances, so the final effect or must be carefully developed if the objects are to be handled at fast speed with secure lifting and without bruising. The third problem is one of hygiene, quality, and customer safety. The issue of hygiene is becoming increasingly essential in terms of human health. Modern robots, however, have accepted all three tasks (Ahmad Nayik, 2015) [1].

Benefits of utilizing robots in food industry

However, the advantages of utilizing robots in food preparation seem exciting. Robots can produce consistent results faster than human employees. Health and safety concerns are also alleviated by robots that may be constructed to withstand harsh circumstances such as high temperatures. Robots, particularly in repetitive tasks such as cake designing or chicken deboning, can assist reduce production costs by delivering higher yields with no need for training or breaks.

Robots provide additional advantages in food production, such as:

Improve quality of food: Since robots work in severe conditions, they can handle this process well where food must be handled at cold temperatures. The robots are also designed to operate in extreme situations, such as extreme cold. A hostile human environment, or even a lack of oxygen, is not a concern for robots.

Increasing product Consistency: Using food robots saves waste and improves total productivity by making measures like cutting more consistent. The robots are expected to help producers gain a 3% improvement in cases where precise cuts mean the difference between infected meat and labelled items.

Adding functionality: The robots can make adjustments that cannot be made by the operator. The robots not only encourage the environment to be disinfected, but it also calculates more accurately during the production process, allowing the traceability of a contaminated package.

Improved worker protection: Robots can use sharp and dangerous equipment to eliminate the need for workers and make the workplace safer.

Improving productivity: When there is a shortage of employees, robots may be required to perform repetitive and physically demanding tasks in an uncomfortable atmosphere that workers would struggle to complete. Robots work in monotonous conditions where employees often feel bored or exhausted.

More Convenience: To accommodate their changing lives, customers are searching for smaller, more comfortable packaging, while manufacturers are looking for more flexible methods of packing mixed or numerous orders on one pallet. (Anonymous, 2020a) [1].

Classification of Robots

They are classified according to many characteristics, such as whether they are stationary or mobile, or whether they are industrial, service, or harvesting robots. Robots are often classified according to their kinematics, or mechanical arrangement. The most common types of robots use in the food industry are:

Classification with respect to Kinematics

Portal robots: Robots are three linear shaft-mounted robotic systems that cover a cubic handling area. Above the mount is the actual kinematics of the robot.

Articulated robots: Articulated robots are industrial robots that have numerous interacting jointed limbs that can be fitted with grippers or tools. Because these arms can move in three dimensions, articulated robots are extremely versatile. They can provide up to six degrees of freedom, depending on how many axes they have, allowing nearly any combination of movement. One limitation of articulated robots is that their range and load capacity are often limited.

SCARAs robots: SCARAs stand for Selective Compliance Assembly. Robot Arms, or SCARAs, are a particular type of articulated robots. They have only one articulated arm that can move horizontally. They function in a similar to human arms and are commonly called ‘horizontal articulated arm robots’. SCARAs operate in series, with each arm linked to only one other. Recent examples of robots use in industry include SCARA pick and place robots and spider robots for high speed picking and placement of light weight goods. SCARA robots is a stationary robot, commonly known as horizontal articulated arm robots, its reliability for rapid and repetitive movements makes it suitable for loading and unloading packaging.

Delta robots: Spider-like delta robots — a type of parallel robot – typically have three to four articulated axes with fixed actuators These robots have a low inertia since their actuators are located in the base. This enables extremely high speeds and acceleration. Delta robots are designed for high-speed handling of lightweight objects and provide minimal maintenance due to the elimination of cble harnesses and the absence of many axes Many food manufacturing procedures employ parallel robots. Again they offer high speed transfer food stuffs, primary (unpacked) or secondary (packaged) through manufacturing lines and a several processes.

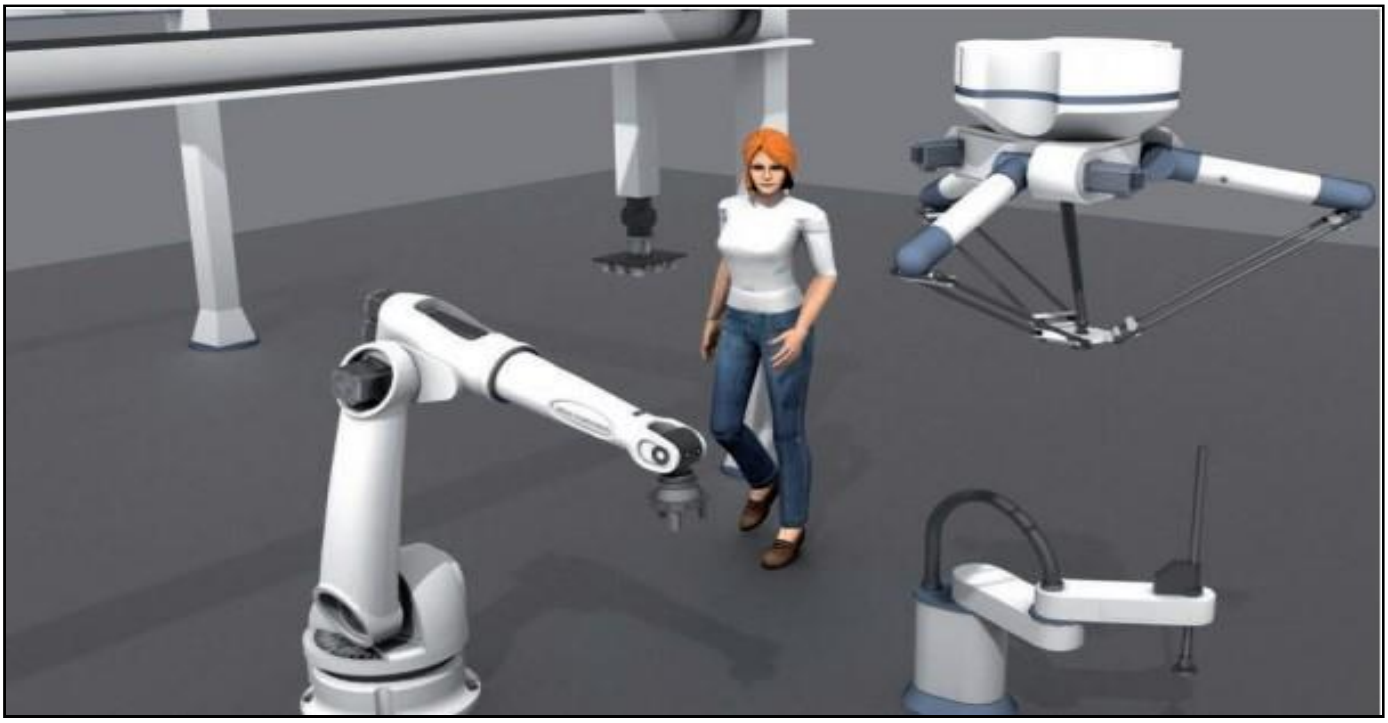

Fig 2.1: Types of robot with respect to kinematics

Classification with respect to application in food industry

Pick and place: The food handling category is currently experiencing a big trend of using robots to transform traditional food industry procedures. This category includes robots used for picking and placing food products as well as meal preparation. According to hygiene regulations, the portions of the robot that come into touch with food must be rust proof, washable, and resistant to extreme temperatures, high humidity, soiling, and mechanical stress. In addition, the cutting elements should have smooth transitions with rounded corners and a joint-free design to avoid cleaning transitions and associated joints. Its primary application is in high-capacity collating, picking, and positioning of products, as well as other related operations (Khan *et al*., 2018) [7].

Palletizing robots: The second category includes applications for packing and palletizing in the food business. These robots are used to palletize cookies, beverages, pasta, candies, and other culinary items that are piled. For example, a created method enables the production of 200 bags weighing 20 kg each per hour and stacking them to reduce freight expenses. Companies that have used such robotic methods for palletizing have completely eliminated the use of wooden pallets from the process, allowing them to use the maximum capacity of shipping containers another advantage of this robotic use is the elimination of bag damage. Pallet management is also managed within the robot cells by specific software and tooling. Using vision sensors, this configuration detects the stack height of individual pallets as well as the orientation of the bins and cartons in the pallet, allowing it to handle both bins and pallets (Khan *et al*., 2018) [7].

Packaging and labelling robots: These robots specialize in food packaging and labelling. The FANUC LR Mate line of robots is well-known for labelling and packaging applications. Wrap labeler's feeds blister packs while the label is wrapped around the part. It is washable because it is intended for food preparation and handling, and the gripper comes into direct contact with the food. These meal preparation robots are available with simulation software such as e.g. The Delta robot (Khan *et al*., 2018) [7].

Product Inspection and Testing: It is common practice to use purpose-built robots for product inspection and testing. In a regular setup, the inspection and testing comes after the labelling robots wrap up their work and the item is ready for packaging. Inspection is typically performed using numerous cameras to ensure the required quality of the end product, such as label inspection on a part. Failed components are rejected and sent to the recheck bin, whilst finished parts are transported to the market through the conveyer belt. The presence of an item within the package is also checked and tested using a camera to assure quality control. (Khan *et al*., 2018) [7].

Cooking Robots: These robots are directly utilized to cook chef robots are appropriate for hard and hazardous conditions, such as in front of an 800 ^{0}C pizza oven. They are also exciting to look at when used to make loaves in front of guests. The vision-based actuation control not only provides a neat and tidy handling, but it also saves the human operator from burning their hands if they accidently touch hot plates Many fast food restaurants, such as Pizza Hut and McDonald's, seek to offer entirely robotized food manufacture, with few humans just taking care of the robots working in food preparation to ensure food quality and timely delivery (Khan *et al*., 2018) [7].

Serving robots: Recently, robots have been utilized in restaurants for customer service and food distribution. Some prototypes are also in use for demonstrations of this intriguing technology, which is connected to a shift in human lifestyle as well as an As a result, human system integration concepts must be addressed. Sushi restaurants in Japan have begun to offer automated food lines to clients, which have grown in popularity. The blooming concept of robot servers/waiters has emerged, but it still need commercial success in order to move forward. (Khan *et al*., 2018) [7].

Main components of an industrial robot

Controller: The robot controller is a computer that is linked to the robot and functions as its "brain." All industrial robots require a controller in order to function. The controller is used to direct the robot on how to work via code, which is also known as a programme. A teach pendant is used to enter robotic programmes into a controller. After the program is entered into the controller, it will transfer the programme information to the robot's CPU. The CPU is a tiny chip installed within the robot that allows the robot to process and operate the program.

Software: Operating system, robotic software and the collection of routines.

Sensors: Sensors allow the industrial robotic arm to obtain information about its environment. They may provide limited vision and hearing for robots. The sensor takes the data and transmits the data electronically to the robot under the control. These sensors can be used to prevent two robots working in close proximity to each other from colliding. Sensors can also help with the end effect by compensating for variations in the room. Pick-and-place robots can use visual sensors to distinguish between goods to be picked and goods to ignore.

Industrial robot arms: The size and shape of industrial robot arms may vary. The end effector is positioned by the industrial robot arm. With the robot arm, the shoulder, elbow, and wrist move and twist to position the end effector in the exact right spot. Each of these joints provides the robot with an additional degree of freedom. A simple three-degree-of-freedom robot can move in three directions: up and down, left and right, and many industrial robots in companies nowadays are six axis robots.

End effector: The end effector is attached to the robot's arm and acts as a hand. This component has direct touch with the substance that the robot is manipulating. A gripper, a vacuum pump, magnets, and welding torches are examples of effectors. Some robots can change their end effectors and can be programmed to do a variety of jobs.

Drive: The engine or motor that pushes the links into their proper locations is known as the drive. The parts between the joints are referred to as links. Industrial robot arms are typically powered by one of three types of drives: hydraulic, electric, or pneumatic. Hydraulic drive methods provide a robot with tremendous speed and strength. A robot using an electric system has less speed and strength. For smaller robots with fewer axes of movement, pneumatic driving systems are used. Drives should be frequently inspected for wear and replaced if necessary (Anonymous, 2020b) [2].

Application of robotic in dairy and food processing industries: Although it has significantly less robotic participation than the automobile industry, the food business is a highly competitive manufacturing sector. This is because food products vary widely in shape, size, and structure, offering a considerable difficulty for manipulator development. Commercial use of robots in the food industry has so far been broadly dispersed at the end of production lines such as packaging and palletizing. Robotics, on the other hand, has a wide range of possible applications in food processing, including product grading, pick and place applications, packing and palletizing, meat, dairy, and baking lines that can handle hot trays.

Meat processing

For many years, experts have been investigating the possible applications of robots in the meat processing industry. The main goal of using an industrial robot is to reduce production costs and occupational injuries while increasing process efficiency and hygiene. The strength of robotics, particularly in boning rooms where labour costs are inherently high, lies in their ability to do repetitive tasks more efficiently and consistently than is now possible. Using advanced imaging technology and a robotic cutting arm, Georgia Tech researchers developed a device that debones chicken and other poultry items autonomously. This robotic system is used for intelligent chicken cutting and deboning as it prepares to slice through the bird's shoulder joint, cutting close to the bone to optimize breast meat supply while ensuring food safety by avoiding the creation of bone chips. Robotic technology was first used in cattle processing to separate complete carcasses into carcass sides. The meat is cut, packed, and shipped to the consumer after being chopped and deboned. These procedures are being accelerated by vision-guided robots to guarantee that the components are accurately portioned and cut, while packing equipment is incorporating volumetric scanning technologies. (Prasad, 2017) [10].

Packaging and palletizing

This robotic system is used for intelligent chicken cut and deboning as it prepares to slice through the bird's shoulder joint, cutting close to the bone to optimizes breast meat supply while ensuring food safety by avoiding the creation of bone chips. Robotic technology was first used in cattle processing to separate complete carcasses into carcass sides. The meat is cut, packed, and shipped to the consumer after being chopped and deboned. These procedures are being accelerated by vision-guided robots to guarantee that the components are accurately portioned and cut, while packing equipment is incorporating volumetric scanning technologies. (Prasad, 2017) [10]. Beyond handling unwrapped products, robotic packaging systems have successfully been implemented in:

1. Place product into feeder of side-loading cartons
2. Place product directly into stacked cartons
3. Fill product bags according to form, filling and stamping machine
4. Create rows or stack products in input to the bagging operation
5. Loading and unloading in the autoclave
6. Unloading bottles from bulk for filling, capping and labeling machines
7. Pack product into accessible trays reuse or single use
8. Unloading baked goods from molds
9. Loading and unloading single-serve packages from filler
10. Packing and desalting beverages, crates, bags, crates, cartons, loose containers, cans, packages, etc. (Ahmad Nayik, 2015) [1].

Robotics in Fruit and Vegetables Processing

The first automatic grading facilities for fruits and vegetables became available more than a decade ago. Machine vision and near infrared (NIR) technologies, as well as mechatronics and computer technologies, have lately been employed to improve the sophistication of these facilities, allowing them to be used for a wide range of agricultural products. Robot technology has shown capable of handling agricultural items with care and precision, as well as gathering data to create a product database for each season. For nearly 10 years, packing and palletizing robots have been utilized in fruit grading facilities, whereas grading robots (Kondo, 2003) [9], which collect round-shaped fruits and inspect them using a machine vision system, are now being used in a number of East Asian countries. Agricultural robots and autonomous systems, which can keep an accurate record of their actions in databases, also play an important role. They then use that information in the next operation or save it for future use by the manufacturer in decision-making or to provide traceability information for quality certified items (Kondo, 2003) [9]. The Agribot approaches the fruit harvesting difficulty by combining human and mechanical operations. A robot-based grading system for deciduous fruits such as peaches, pears, and apples has been developed. The device picks fruit from containers and inspects it from all angles (Kondo, 2003) [9]. The grading robot's top speed is 1 m/s, and its stroke is approximately 1.2 m. It takes the robot 2.7 seconds to transfer 12 fruits to trays, 0.4 seconds to move down the conveyor line, and 1 second to return once the fruits have been discharged. The method takes 4.25 seconds in total, including 0.15 seconds spent waiting for the next batch of fruit. This means that a single group of robots can process approximately 10,000 fruits every hour. (Kondo, 2009) [8].

Robots in freezers and ovens

When handling food, robots are placed in freezers or near ovens; while these settings do not normally hurt robots, some protection must be provided to guarantee the robots perform efficiently. Palletizing robots based inside freezers prevent undesired frosty condensation from forming on ice cream packets. (Prasad, 2017) [10].

Challenges and opportunities in the food industry

The difficulty in incorporating robots into the food business originates from the fact that raw materials may not have standard measurements that can be programmed into a robot. A robot built to peel an apple, on the other hand, is more difficult to programme because no two apples are the same size (Chrisandina, 2018) [4]. It should come as no surprise that robots are still mainly used in the food and beverage industry for 'heavy work', i.e. for packing, repacking and palletizing. Normally the products involved are packaged foods. Handling these is relatively straightforward and can usually be done with a standard model chosen from the broad spectrum of robot designs. However, before robots were able to perform tasks in the actual production of food, and therefore to come into direct contact with food, huge hurdles had to be overcome that also demanded a re-think among the robot manufacturers. After all, food products are made from natural ingredients that cannot be standardized, have specific rheological properties and are often highly sensitive to mechanical interference.

Moreover, the required degree of product safety and length of shelf life calls for stringent hygiene practices that meet the relevant cleaning and disinfection requirements, and this applies equally to robots. The environmental conditions in food production are often complex: both food and machinery can be the source of corrosive properties (water, acid, salt and other chemicals etc), while the ambient temperature can range from extremely hot to well below freezing. However, it was exactly these conditions that made the use of robots in the food and beverage industry sensible and desirable. The driving forces behind this argument were the humanisation of the working world and the further improvement of food safety by stepping up efforts to implement hygienic practices in production. Then there was the ongoing challenge of maximizing efficiency and minimizing costs. Who would want to spend eight hours a day performing the same action over and over again at a temperature of 8 °C? Who would want to spend the best part of their day working in a freezer? And how are we supposed to permanently exclude the potential for microbial contamination from contact with human skin? How it is possible to guarantee a standardized production process not just over eight hours, but over 24 hours?

The food industry is mainly made up of small and medium-sized companies with extensive product ranges. This, coupled with the associated need for flexibility at various levels, means it is crying out for the technological solutions that robots can offer. An inarguable point with regard to the use of robots in production is that if they are to work directly on and with food, it must be possible to clean them properly and with the usual means and methods, and, where required, to also disinfect them. A variety of solutions have been adopted to ensure the hygienic design of food-grade robots: while 'wash-down robots' have an IP65 hygiene cover that's easily washed down and changed, manufacturers of other variants opt for protective coatings such as epoxide, or they make their robots entirely out of stainless steel, which does not react with cleaning agents, acids or alkalis. The lubricants used with these robots are also food-grade (certified NSF H1). Despite all this progress, there are undoubtedly many more advances and improvements that are possible in the development of food-grade robots (DLG-Expert report 1/2015).

Conclusion

The challenges faced by different sectors of the food processing industry largely depend on the raw materials in each sector and whether the product must be delivered continuously or in batches. Giving robots the ability to evaluate each raw material before processing could be essential in key processes, while training staff to work alongside robots could be a bigger issue in processes, secondary. Overall, the food industry must consider not only where robots can be a profitable investment, but also how to shift its employees away from the roles robots take on (Chrisandina, 2018) [4].

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