AUTOMATION INTERVENTION: AN OVERVIEW OF ROBOTS IN FOOD PROCESSING INDUSTRY

Abstract

The food manufacturing industry is one of the key manufacturing sectors across the world and is a vital strategic element in all national economies. Currently, it's fifth most automated industry in the organised sector, but it has one of the lowest levels of robotization i.e. 3%. Previously, Industrial robots were only used for packaging and palletizing, now numerous types of industrial robots are currently being utilized in food processing industries (FPI), generally they are focused on the handling high-volume but single-product lines. The availability of highly effective robots, such as the Delta class of robot swiftly perform pick-and-place operations with food products on the production lines and, Articulated robots carrying out specific tasks that demands high level of dexterity and strength. The major advancement in the use of industrial robots is the ability to handle products that are not wrapped, it includes stacking pancakes, waffles, bread, and pizza dough before loading them onto a conveyor or feeding into a wrappers machine. Modern manufacturing techniques like three-dimensional (3-D) printing has simplified the designing and manufacturing of complex grippers used for precise and soft handling of delicate food products. The lighter, compact, and smaller gripper reduces the mass of the tool, allowing for better product handling with less wear and tear. These robots also comply with IP67 rating that makes them more hygienic with no ingress of dust and water in it. The application of industrial robots does not only increase the productivity, but also ensures the food safety and security. Cobots are becoming an essential component of the FPI, particularly in the service sector. With the inclusion of cyber-physical systems (CPS), human operators could instruct robots to carry out activities, ensuring the significant role of industrial robots in the Industry 4.0 revolution.

Keywords: Automation, Food industry, Food safety, Industrial robots, Processed food.

Authors

Lalita
APPD, ICAR-Central Institute of Agricultural Engineering
Bhopal, India
lalitapfe@gmail.com

Puneet Kumar
ICAR-Central Institute of Temperate Horticulture Srinagar, India
puneet.kumar1@icar.gov.in

Om Prakash
ICAR- Central Arid Zone Research Institute
Jodhpur, India
Om.prakash13@icar.gov.in

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I. INTRODUCTION

In 2011, the world population surpassed seven billion and according to the most recent estimates, the population will reach 8 billion by the end of 2022 and 9.7 billion by 2050 [1]. Due to a decline in the birth rate and an increase in the population of people above 65 years, the world's median age is rising at a faster rate. It is currently 31 years, and in 2050, the same is expected to rise to 36 years. The rapid increase in population suggests that there will be a significant increase in food demand in the near future. In order to efficiently meet the future demand, there is an urgent need to expand food production by 70% by 2050. But the production is not the only concern now, the rapid emergence of newer communicable and non-communicable diseases is tending towards demand for varied preferential dietary needs. In addition, food losses at all phases of production and consumption are a major concern. According to Reference [2], one-third weight of the total produced food goes waste across the globe with an estimated value of US $940 billion. This degree of inefficiency negatively affects the environment, the socio-economic system, and food security. Converting the raw material into a form that would enable it to have a longer shelf life is one of the best strategies to minimise these losses. Moreover, nutritional value is preserved with enhanced palatability, extended shelf life, while ensuring safe food supply. Food processing is one of the tangible means of reducing food loss and increasing food supply. The global food processing industry is valued at over US $2 trillion and consists of over four lakh distinguished businesses. The food processing sector is now more varied and intricate than ever. Since 1950, the number of people living in metropolitan areas worldwide has increased from 751 million to 4.2 billion in 2018. The urbanization is prompting people to move in big cities in pursuit of employment and improving their standard of living. The life is moving at very fast pace in big cities and left with fewer time to be spent on preparation of food at home. Feeding huge population with varied dietary needs and preferences is becoming global societal concern. It leads to huge amount of food wastage due to inadequate storage facilities. The food processing sector is one of the most dynamic businesses due to continually changing trends in goods and consumer demand. The majority of issues in the food processing industry can be resolved through contemporary technologies.

The FPI employ a wide range of cutting-edge modern technology and ensured productivity enhancement [3]. Robotics is one of the technologies greatly benefiting the food processing sector especially in handling, packaging, and serving. The food processing sector is currently the fourth most automated in the organised sector, but it has one of the lowest levels of robotization overall. The Czechoslovak word "robota", means “forced labour”, and is origin of the word "robot". Generally, a manipulator with multiple degrees of freedom and the ability to be reprogrammed using a high-level language has been referred to as a robot. They are a relentless labour force, capable of completing activities at a steady pace, resistant to the effects of repetitive stress injury, fatigue and lacking the need for pauses. Robots can carry out a number of jobs with the help of the right software and a variety of tools. The industrial robots may have three to seven-axis arm with a serial or parallel configuration. Each joint may be actuated by a computer-controlled electric, hydraulic, or pneumatic drive system. A central controller offers a way for the robot's joints to be activated in order to carry out particular actions. Through the use of an input/ output device or a serial/ parallel communication line, the controller can also be interfaced to other components or systems. The controller then gives the operator or programmer a way to communicate with the system [4]. In food processing, the most important desirable characteristics are cleanliness, safety

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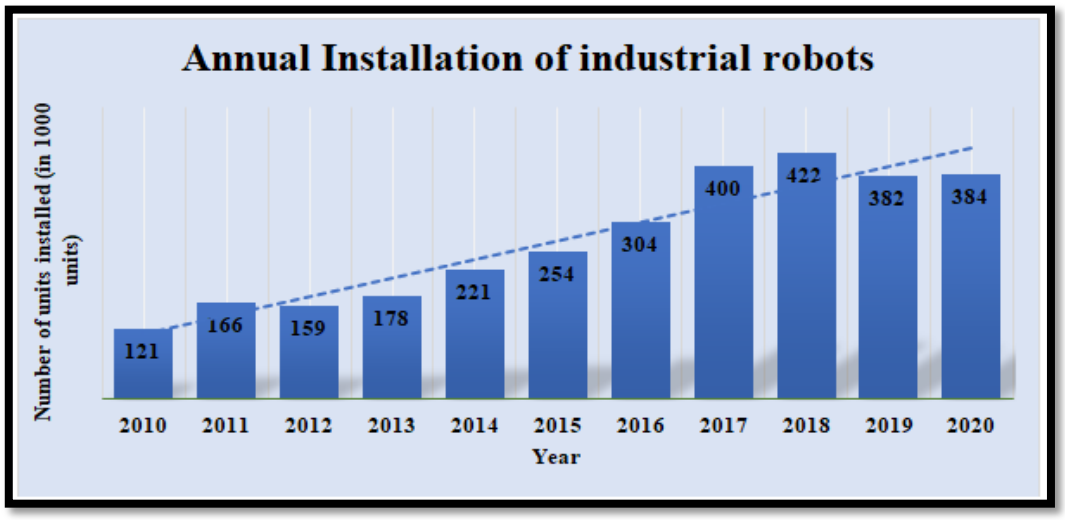
and hygiene. The majority of industrial robots have an IP-67 rating, which offers protection against any dust ingress and full submersion in water with no ingress [5]. High-pressure hot water and other chemical agents are frequently used in the cleaning process inside the industries. The industrial robots, its controller, and the ancillary equipment must be built to withstand the environment and conditions for cleaning in place. The system's design must adhere to all legal standards and guidelines for equipment used in food processing. It is necessary to develop unique end-effectors and sensors to handle the variety of activities and the variability in the shape, size, and characteristics of the products. The more demanding or highly skilled tasks may be mechanised through the integration of various technologies and the application of intelligent software with some learning capability. The selection of end effectors, the capabilities of sensing technologies, and the corresponding software, and manipulator control techniques all play a significant part in the handling and processing of more diverse products. Integration can produce workable solutions in practically every situation, although applications in food processing have not yet been fully exploited. A "food robot" is a robot that replaces farm workers in the automated food business. Robots are perceived as a potential option to reduce human meddling in the food processing industry, ensure processing quality and safety, and increase productivity, accuracy, and precision. Cobots, also known as collaborative robots, have the potential to drastically change the processing business because this business demands frequent human interaction. As a result, the existing use of robots in industry has a chance to change working conditions in food processing industries if they work side by side.

II. CURRENT STATUS OF ROBOTIZATION

The industrial robot business hampered during 2005–2008 global economic and financial crisis. Over the past ten years, there has been a pretty noteworthy increase in the use of industrial robots in multiple industries as result of the demand for automation and technological advancements. It resulted as 9 percent CAGR in industrial robot installations from 2015 to 2020 (Figure 1).



(Source: World Robotics Industrial Robots 2021).

Figure 1: The trend of worldwide installation of Industrial robots in past decade

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1. **World's sink of industrial robots:** Reference [6] reported that the average "robot density" in the manufacturing business was 126 robots/ 10,000 workers in 2020 compared to barely 66 robots/ 10,000 workers in 2015. Worldwide, the countries with highest robot density are Republic of Korea, Singapore, Japan, and Germany with respective numbers 932, 605, 390, and 371 in 2020. Asia has expanded robot density by an average of 18 percent CAGR over the past five years (2015-20). Currently, Asia has the largest robot market in the world with deployment of 71% of newly created robots, compared to 67% in 2019. According to the estimate, 0.435 million robots will be installed annually by 2021, an increase of 13% from the year before. Worldwide, major markets for industrial robot installation include China, Japan, the United States, the Republic of Korea, and Germany, which altogether account for around 76 percent of total robot installations. China, Japan, and the Republic of Korea are Asia's three biggest markets for industrial robots. In 2020, the number of robots installed increased in China (168,377 units; 20%), whereas the Japanese and Korean markets (38,653 units; -23%, and 30,506 units; -7%) struggled to keep up with the number of installations from the previous year. Since 2013, China has been leading the world in the installation of industrial robots, and in 2020, China accounted for 44 percent of all robots installed globally while robot installations in India decreased by 25% to hardly 3,215 units. The pandemic in 2019 had a devastating impact on the robotics sector, with a record decline in robot installations.

2. **Industry-wise status of industrial robots:** Three factors the continued trend toward automation, technological advancement, and readiness for the fourth industrial revolution—are mostly to credit for the growing dominance of industrial robots. Due to the precise work requirements and handling of heavy and complex machinery, the electrical/ electronic and automotive industries use robots extensively, which comprise almost 50 percent of total robots installed in 2020 (Figure 2). The fifth-largest among the organized sector in the world that uses industrial robots is the food and beverage industry. At the moment, only 3% of all robots developed are intended for food and beverage sector. The number of robots in food and beverages industries is increasing to meet the demand of high throughput and quality product manufactured under hygienic conditions (Figure 3). In 2019, there was slight decrease in number of robots installed in this industry due to the prevailing pandemic situation across the world. This sector is again progressing and reaching the level of pre-pandemic era.

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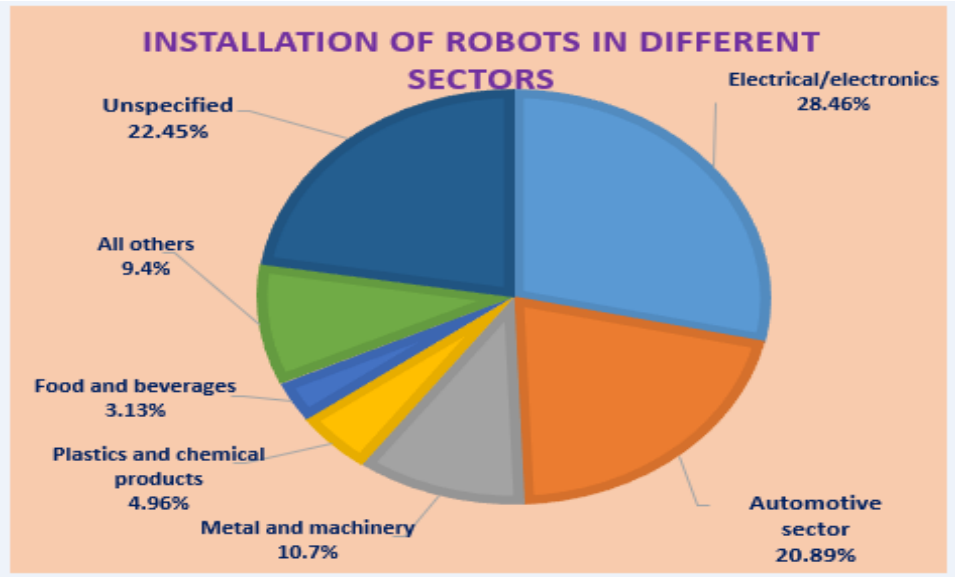
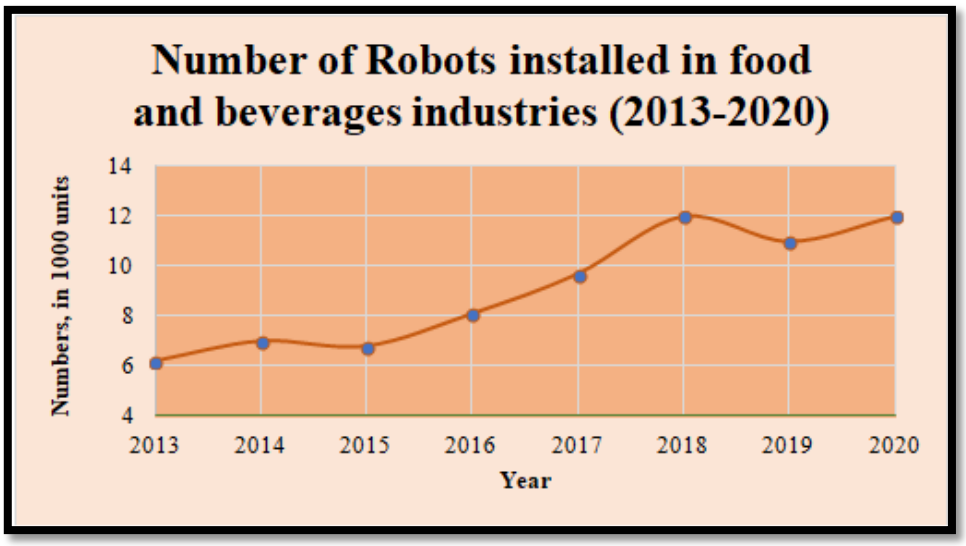


(Source: World Robotics Industrial Robots 2021)

Figure 2: Instead of actual name of industries, category name is mentioned in image.



(Source: World Robotics Industrial Robots 2021)

Figure 3: Robotization of Food and Beverages Industry

In the 1990s, robots were initially used for direct food handling in the bakery sector. These machines were capable of completing simple pick-and-place jobs at a rate of 55–80 cycles per minute. Red Meat, fish, and fowl make up a sizable portion of the food consumed worldwide, yet they are challenging to manufacture using automated methods. It is arduous to produce food, utilizing manual methods due to the goods' flexibility and variety as well as concerns for customer safety, quality, and hygiene. Robotics is essential because it encourages the development of automation and robotization of facilities that can produce meat products, and prevent direct human contact with the product. It could be crucial to remove people from dangerous working environments. Production control and consistency in output, as well as increased productivity, are tangible reasons for using robots in this sector.

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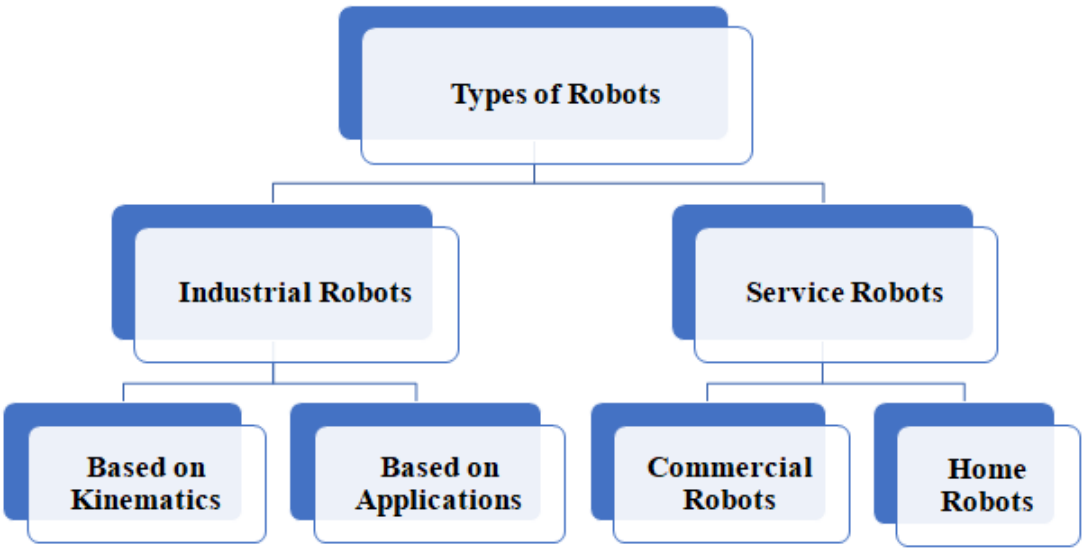
III. TYPES OF ROBOTS

According to the extent of robot's application, they are categorized into two classes of robots: industrial robots and service robots. Industrial robots are utilised in industries where labour-intensive or repetitive operations must be carried out. Typically, these robots work in a space where there are very few opportunities to interact closely with human workers. In contrast, service robots are employed to carry out routine duties for people or to assist the people. They usually operate alongside people and in close proximity to them.



IV. INDUSTRIAL ROBOTS

The third industrial revolution was significantly influenced by industrial robots. It is anticipated that industrial robots will play a significant role in the fourth industrial revolution as well as the future of the manufacturing and service sectors. They enhance the competitiveness of manufacturing, thanks to their innate qualities of quick and accurate operation, quality control, high productivity, and adaptability at minimal cost. The highest robot density is seen in the electronics and automotive industries. A larger share of newly installed robots is utilized in automotive industry, which reached 48% in 2020. However, high-growth industries such as logistics, life science, food and, emerging manufacturing sectors like coating, laser-based process etc. will see higher demand of industrial robots in near future with rising in the demand in these sectors. One of the major industries with the least amount of robotization is the food industry, which accounts for only 3% of all installed robots and is slightly expanding each year.

1. **Industrial robots and their brief history:** Research and development in industrial robot began in early 1950. George Devol filed the first patent application in 1954 and was awarded in 1961. Dovel and Joseph Engelberger founded **Unimation**, the first firm in the world to manufacture robots. Their first commercial product, the *Unimate*, was used on the General Motors assembly line in 1961 to collect and transfer parts from the die-casting assembly line for spot welding on automobiles. Initially, the cost of operation was relatively higher, but as the technology advanced, the use of robots became cost-effective.

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In 1969, Victor Scheinman created a robotic arm with six degrees of freedom (DOF) that is entirely electric and was controlled by a normal computer. Swedish company, **ASEA** (Allmanna Svenska Elektriska Aktiebolaget, translated as General Swedish Electrical Limited Company; now, named ABB) created a microcomputer-controlled robot for arc welding and machining in 1973. Hiroshi Makino created the *SCARA* (selective compliance assembly robot arm) class of industrial robots in 1978. This four-axis arm was ideal for quick assembly of small parts. This transformed the manufacture of consumer goods and electronics in bulk quantity. The human being is considered as aspiration behind the development of industrial robots. The weight-to-load ratio of a human arm, which is 1:1, is used as a benchmark for industrial robots. However, in 2006, **Kuka** produced a lightweight robot with 7-DOF and advanced rapid and precise force-control capabilities. Prior to this, parallel kinematics robots were created in the 1980s and were well suited for high-speed activities like pic and drop operation and managing heavy workloads. Cartesian robots, which typically have three orthogonal translational axes and used in logistics or machine tending, was thought to be the best for covering large workspaces. However, in 1998, Gudel created a gantry type robot with a curve-track and a flex picker robot, which revolutionized the quick picking and placing of food items. Human tasks necessitated two-handed synchronized dexterous manipulation, and the prolonged and repetitive nature of these tasks reduces their effectiveness and precision. In 2005, **Motoman** firm unveiled a two-handed dexterous manipulator, that mimics the reach and dexterity of the human arm. Automated guided vehicles (AGVs), the following class of robots, were developed for transporting components or loading machinery. Initially, they were guided by wire or magnets embedded in the floor. Modern AGVs are equipped with laser scanner-based navigators, which prepare a two-dimensional map of the surrounding area for navigation and fulfilling their task. The operating needs and workspace accessibility are taken into consideration throughout the design and development of an industrial robot. A certain type of robot performs a specific duty in a small area. Industrial robots come in many different varieties, and they can be categorized in a number of ways, including based on their "motion or kinematics", how they carry out tasks, and their "applications". The robots are made to be able to carry out a specified duty in an area that has been designated as their "work envelope". The area within which a robot's parts can move to carry out any duty is known as the work envelope. It is the three-dimensional space that a robot can move across in any direction using its moving parts. The work envelope of a robot depends on its joint range (angular or longitudinal range), size (body, arm, and wrist dimensions), and kind of joints (linear or rotary joints).

2. **Categorization based on motion and kinematics:** The selection of mechanism, its kinematics and computational methods used to determine joint motions and intended application of gripper are all closely related. The choice of kinematics on robots depends mainly on fundamental mechanical requirement like payload and workspace size. The articulated mechanism-based robots are suitable for task which requires working inside or around obstacles. Based on kinematics the robots are divided into two categories: serial kinematic machines and parallel kinematic machines. To obtain maximize stiffness at minimal cost, the end effector or gripper is supported from different directions and parallel kinematic robots has significant advantages. The most of the food industry operation can be done by serial kinematic machines. Nowadays, the parallel kinematic machines are also getting common in food industries. In serial Kinematic machines, all the axes are stacked one over the other. *Autonomous articulated robotic educational*

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platform (AUTAREP) is an example of serial robots and *FlexPicker* is an example of parallel robot [7]. To accomplish the various tasks, based on movement, robots are broadly categorized as fixed and mobile robots. Due to their simplicity and ease of use, stationary robots were initially used in industrial applications. These robots fall into the following categories.

- **Cartesian robots:** The are also known as *portal robot,* they have they prismatic joints that are mounted and moves in three linear axes to span a cubic handling area.

- **Articulated robots:** The are provided with multiple interacting jointed arms (at least three rotary joints) on which grippers can be fitted. As its arms can move in three dimensions these robots offer higher degree of flexibility. Usually, they may offer motion with maximum 6-DOF, and enables almost all types of movement. They come with some restrictions such as low load capacity and limited range, which make them suitable for light weight applications only. One of the largest markets for deployment of industrial robots is China, the articulated robots compose of about 57% of total robots deployed in industries in China.

- **Cylindrical robots:** They are such robots, whose axes form cylindrical coordinate system and their workspace in the form of cylinder.

- **SCARA robots:** These are type of articulated robots equipped with single arm that can perform motion in horizontal direction only. Their mode of operation is like human arms; therefore, they are also known as *Horizontal articulated arm robots*. They usually offer 4-DOF; improved speed and repeatability on pick-and-place tasks. Kinematics of SCARA robot makes it suitable to perform assembly line tasks with tight tolerance, putting shaft into a hole.

- **Parallel robots:** Its multi-joint robotic arm, also known as *Delta* robot. They look alike spider and offers advantages of high speed and acceleration due to small inertia as the actuators are located on the base. They are very commonly found in food processing industries to perform various jobs such as spreading sauce on pizza, pick and place operation of cookies in production line.

3. **Categorization based on their applications:** Robots are designed and developed in such a way that they are capable of carrying out a specific range of duties. There is currently no sophisticated robot performing all the activities as a human worker can. But, advances in robotics and allied sciences of research may lead to the development of such robots in the future. Over the past few years, the use of robots in the food industry has grown significantly, revolutionizing food processing, grading and sorting, picking and dropping, handling and transportation, packing, and palletizing operations. When we talk about how industrial robots are used in the food processing sector, we may divide the activities they contribute into primary and secondary uses.

- **Primary robotic applications in food processing industries**

  - **Pick and drop applications:** All food products vary in size, shape, and rigidity, thus there is a need for carefully constructed, programmable robots or robotic

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arms with a variety of distinct grippers that can be used depending on the product and the work at hand. The location and orientation of the product can now be more precisely determined due to advancements in robotics and machine vision system, which makes it easier to delicately grasp the object and position it in the desired area without risk of product damage.

- **Cutting and slicing:** These operations are simple but monotonous in nature, due to which it becomes hard to maintain the consistency for the human worker. However, the robots are well-trained to carry out the monotonous duty consistently over time. Robots can be programmed to precisely perform cutting and slicing operations to the correct dimensions for the end-user.

- **Secondary robotic applications in food processing industries**

  - **Packaging and palletizing:** After the product is processed and quality checked, the following step is to pack the product in desired primary, secondary, or tertiary packaging. After packaging, the items are palletized on a shelf inside the warehouse for convenient handling during subsequent market supply. Robots are used for 40% of palletizing operations and 26% of food and beverage packaging in the food industry.

  - **Product decoration:** Robots might also be used to do aesthetic tasks like decorating chocolates, rice cakes or pastries, or decorate pizza. The increased DOF and wider range of motion enable the robots to carry out decorating tasks with great efficiency.

V. APPLICATIONS OF INDUSTRIAL ROBOTS IN FOOD PROCESSING INDUSTRIES

It is not exaggerating to say that the food processing industry is currently one of the key industries using the most automated systems. This is only possible because of the high level of innovation in contemporary science and technology, which includes the use of personal computers, microcontrollers, machine vision systems, sensing technologies, and robotics. Robots for packaging and palletizing were only utilised in the food grading industries at the beginning of the 21st century [8], but as technology advanced, grading robots that used machine vision and artificial intelligence (AI) have grown more prevalent [9]. Robots are now being used more and more in the food industry as a result of recent innovations in comminution, mobility, adaptability, machine vision, and end-of-arm tooling (EOAT) over the past few decades. The food processing industries can be broadly divided into the minimally processed fruits and vegetables, drinks and beverages, bakery, meat, poultry, and fish, dairy, sugar, and edible oil industries, confectionaries, cereals & pulse mills, breakfast cereal sectors, etc. Below are a few examples of how robots are being used in the food processing industry.

1. **Bakery:** The bakery sector does not produce only a single item; instead, its product range might change from day to day and season to season. The major advancement in the use of industrial robots in the food processing industry is the ability of current robots to handle products that are not wrapped. These robots are capable of performing a variety

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of tasks, including stacking pancakes, waffles, bread, and pizza dough before loading them onto a conveyor or feeding into wrapping machine. One of the most difficult tasks is controlling product while releasing on stacks or shelves, but 3-D printing has simplified EOAT design, while lowering production costs in the process. When it is necessary to handle delicate soft pastries, cakes, muffins, etc., the flexibility of EOAT has revolutionised the bakery sectors. With EOAT technology, altering merely the gripper and a small amount of programming is enough to switch the robot into executing a new task. Articulated robots are capable of carrying out specific tasks that demand for a high level of dexterity and strength. They are also appropriate for operating in extreme temperatures. With integration of food grade grease and IP67 rating, the *Motoman GP4* is a small articulated robot that can do tasks with greater flexibility. For handling bakery and snacks, Syntegon Packaging Technology has created a robotic pick-and-place platform that is integrated with Delta class robots. The *M600* robot, which was developed by ABC Packaging Machine Corp., is a high payload, 2-axis industrial robot that can handle almost every pack configuration, including cartons, semi-rigid containers, flexible packages, and bags, among others. Robots are utilised in the packaging process on the biscuit production line. One robot picks up the biscuits and places them in a blister tray; a second robot packs the blister tray into retail packs. These robots feature "Dual check safety" (DCS) software, which keeps them in the right position and speed in relation to the conveyor's speed and biscuits' orientation. At temperatures above 1200 °C, magnetic grippers are utilised to handle pastries and baking tins. Due to their lower maintenance requirements and longer lifespan (>1 million cycles), magnetic grippers are preferred over vacuum grippers in these applications. Bedford-based Soft Robotics Inc. has developed an improved version of the mGrip Modular Gripping System (EOAT) with an IP69K rating to allow for the secure handling of food goods. Tighter grip spacing is made possible by the improved EOAT technology, which further enhances pick and drop performance for smaller items. The lighter, more compact, and smaller gripper reduces the mass of the tool, allowing for better product handling with less wear and tear. A camera equipped with a computer vision system is capable of creating a 3-D map of the cake's surface, which may then be used by the computer to determine the robot's tracking path while frosting.

To prevent cake deformation, these robots accurately adjust the distance between the "Icing gun" and the cake's surface. Robots are equipped with an ultrasonic knife installed on a multi-axis robotic arm that can provide a complex motion profile to cut, while synchronising with the conveyor's speed. When handling muffins, a gripper of the needle type that has a handling capability of 1300 muffins per minute is employed. At a rate of 120 picks per minute, vacuum cup-style grippes are employed to handle the baked bread from a moving baking pan. Foster Bakery (Barnsley, UK) successfully implemented the *FANUC M-710iA*, an articulated robot, in a reel oven where the shelves continuously move, necessitating the replacement of the shelves holding baked goods with shelves holding freshly formed dough. Because it is impossible to manually spin all of the shelves, so some of them rotated without being loaded. However, by using this robot, the unloading and loading process can be completed in less than two seconds. This robotic system increases manufacturing capacity by 80% while reducing energy use by 50% [10].

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2. **Meat processing:** As studies suggested that meat packing is one of the most hazardous tasks in the slaughtering business, several types of caresses must be handled in order to preserve its ideal texture and dimensions. With the aid of sensors, industrial robots have been built to respond to the different characteristics of animal carcasses. Before sending each carcass through the cutting process, their dimensions are calculated. This enables the robot to chop meat precisely even at fast speeds, eliminates the need for human personnel to oversee this risky component of the operation. Splitting a carcass is a very laborious task that demands a lot of force, and after a while a person cannot continue to work with the same speed and accuracy. For these reasons, automation in splitting operations is highly desired. Reference [11] has created a robotic cell for cutting ham bones and quartering cattle carcasses. Meat processing involves repetitious and physically strenuous labour and maintains it requires hygiene and quality control. Vision system in the robotic cell determines the cutting path, and force control sensors are used to keep the cutting blade's distance from the spinal cord constant [12]. With a built-in vision system, the robotic arm may also be used to remove the hocks from carcasses. The cutting tool is immersed in a hot water tank for sanitization following each cycle. These robots are capable of picking up stunned chicken off a conveyor belt and anchoring it to a shackle in robotic handling of stunned poultry. This optical system can also detect if a bird is lying with its breast up or down followed by determining the bird's centre of gravity and position it in relation to the robot.

3. **Sorting and grading of horticultural produce:** Mechanical sorters and graders integrated with conveyors are used in automated sorting and grading operations to categorise items based on weight and dimension. These mechanical sorters are unable to find bruises, minor defects, or instances of microbial contamination. Robots that have vision systems built into them are more reliable in separating high-quality fruits and vegetables from the rest of the load and throwing out undesirable or spoiled items [13]. The advanced deep learning algorithms speed up and improve the accuracy of sorting and grading operations, making them even better than human eyesight. By fusing a vision system and artificial intelligence, Gearbox Innovations created two classes of robots: the *GearVision sorter* and *GearVision inspector*. *GearVision sorter* is used as an in-line sorter to separate products based on their visual quality. *Gear Vision inspector* is a stand-alone robot that can thoroughly assess the quality of fresh produce. Grading is the process that divides horticultural produce into different grades and necessitates the knowledge and experience of an individual. A mechanism for automatic examination had been created by [14]. It can grade 9000 fruits each hour by sucking up to 12 fruits at a time and capture photographs of the top, bottom, and sides of each one in 4.5 seconds per cycle. In the series of it, [15] created a gripper based on Bernoulli's principle for handling delicately sliced fruits and vegetables. The gripper makes it possible to lift objects with little contact area, reducing the risk of contamination and damage. Dust and moisture on the object's surface can also be removed using the robot's air stream. Using an image processing technique to extract feature information including projected area, perimeter, feret diameter, and roundness, [16] created a machine vision system capable of classifying mango fruits into small, medium, and large classes.

4. **Food packaging:** Despite the fact that robots have long been used in various aspects of the food supply chain, they have only lately improved to the point where they can fully automate the packing process. This entails a shift to robotics for all of a facility's

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traditional contact points, including depalletizing, unpacking, and primary, secondary, and tertiary packaging. Bottle filling, for example, has historically required human involvement to individually inspect incoming materials before the filling process and then examine the final product afterward. However, this role can be managed automatically in-line by robots, to examine whether bottles are filled or not. The robots are now also capable of handling unpackaged food items like cheese, meat, and poultry as well as bottles, trays, cartons, and other containers for food and drink. In fact, compared to humans, robots are capable of carrying out their tasks with higher accuracy and precision that too in less time. For handling of big volume of pancakes, Honeytop Specialty Foods by RG Luma (United Kingdom), developed a delta robot, *FlexPicker*, it ensures that all pancakes are selected and stacked quickly, precisely, and hygienically. Yaskawa Motoman introduced GP series of robots suited well for doing primary and secondary packaging tasks. Since, these robots are equipped with 2-D or 3-D vision systems so, these robots can operate well in lights-out condition (without human interaction).

5. **Warehouse or storerooms:** Autonomous guided vehicles that can carry items on their top, tow objects behind them in trailers, or both are employed in warehouses and storerooms. A selected handful of these vehicles also have grippers to hold the stuff. Such robots are equipped with navigation systems to complete their tasks efficiently, quickly, and precisely. It also avoids colliding and interfering in the line of work of other robots. Because mobile robots have trouble reacting to unanticipated interference, they are typically deployed in highly regulated situations like production lines. The food products come in a variety of sizes and shapes, and some may be more delicate to handle, and they require specialist grippers, it's not easy task to develop a lot of grippers and replace when needed. Keeping this in view, a universal gripper that can be used for a variety of objects, independent of their shapes, was created by [17], also RTS Flexible System developed a multi-product handling robot to pack delicate goods like poppadoms, strawberries, peaches, etc. JLS Automation, York, has created the Peregrine carton box loading and closing robot, which offers carton control from forming through closure without turns or conveyors, and supplied to downstream at high speed. Industry need has transformed the robotic research sector. Festo has recently developed entirely new gripper concept using laser sintering technique, the "Fingripper", which adopt the product being handled that ensure the gripping of fragile and soft products.

6. **Application in diary industries:** The automatic milking systems are referred as robotic milkers, first developed in Europe, and become commercially available in 1992. They are voluntary milking system that allows cows to set her own milking schedule. Each cow is fitted with electronic tag, when the cow enters robots, the robotic system read its tag and after successfully identifying her that start cleaning of her teats, hitch milking cups and start milking. After completion of milking, each milking cup is removed and cow leave the robot [18]. These robots are already frequently employed for milking dairy animals, and it is anticipated that by 2025, 50% of the dairy industry in the European Union would be robotized [19]. The global milking robot market is projected to grow at a CGAR of 11.4%, reaching a market value of US $2.94 billion by 2027. Other than milking, robots are also used in cheese industry for cheese packaging, and cheese and curd slicing. Fanuc Robotics' *M430iA/2F* robot can integrated with packaging and conveying equipment. These robots provided with gripper to handle delicate vacuum-packed cheese by picking

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and placing on the conveyor and can also align packed cheese on second conveyor for labelling.

7. **Application in drinks and beverages industries:** Drinks and beverage industry is one of the most widely distributed, diverse, and automatable sectors among food industries. This sector is known for its extensive use of robots and has the potential to have same impact on the robot market as the automotive and electronics sectors. Robots are an excellent choice for deployment in this industry due to their robustness, extensive functionality, and high level of reliability. Robotics are now produced and sold at half price as compared to 20 years ago with exponential improvement in efficiency. ABB's *FlexPicker* can perform pick and place operations at an extremely high-speed relative to the manual operation. *Fanuc M-430iA* is built to operate in the food industry's close-quarters and high-care environments. Modern robots are equipped with cutting-edge technologies like advanced software and machine vision systems, enabling them to make decisions much like humans. The vision system built into robots allows for quick and accurate picking of products that are randomly oriented on conveyors. This vision system is installed to provide the ability to monitor the conveyor and product placed on it, allowing the robot to deal with moving conveyor. The user interfaces for the picking and palletizing robots are offered to make the system simpler to use and customise operational requirements such as defining the box or pallet dimension that increases the efficiency of the palletizing activity.

8. **Inspection and quality assurance robots:** Due to the occurrence of endemics brought on by intake of food that is unfit for consumption, quality assurance and the production of processed products in hygienic/aseptic environments have come under scrutiny. The consumer's increased awareness of health and wellbeing and expectation that producers supply products of proven quality may be the driving force behind this. Like any other industry, the food processing sector faces unique challenges when it comes to quality inspection techniques. Products must undergo routine inspection based on their external and internal qualities, and non-destructive methods are becoming more and more important to determine whether a product is fit for human consumption. Sensor-based quality inspection is expanding due to its non-destructive nature, which is used to analyse internal quality. It includes sugar content, rotten core, bruising, incidence of microbial growth, acidity, and rind puffing, as well as any other internal faults [20].

VI. COLLABORATIVE ROBOTS OR COBOTS

Collaborative robot use is growing quickly because they are ideal for repetitive, difficult work in small to medium enterprises. The Industrial robots are often designed and installed to do repetitive tasks in designated workspace whereas the cobots can perform diverse tasks and ensure the safety of human working alongside the robot. Unlike industrial robots, the cobots are typically smaller in size and designed with in-built safety consideration. These robots are equipped with proximity sensors and simultaneously monitor their workspace, that helps in slow down or stop altogether when human worker comes near to them [21]. As a result, these robots don't need as much workplace supervision as industrial robots do. This ability has come at the expense of operation speed; typically, they move their arms at a rate of 10 to 15 times per minute, which is slower than their counterpart. The *Motoman HC10XP* is a cobot that can be easily integrated into environments where regular

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industrial robots cannot operate safely. Although, the cobots are capable of doing diverse tasks in large workspace, the current way of utilization of cobots restrict its use in narrow set of predictable operations [22].

VII. SWOT ANALYSIS OF ROBOTS IN FOOD PROCESSING INDUSTRIES

By 2028, it is expected that the industrial robot market will be worth millions of dollars, but getting there won't be simple. The secret to realizing the true potential is to execute the right techniques (Table 1). The SWOT (Strength, Weakness, Opportunities, and Threat) analysis is one of the methods used for strategic planning and determining the best course of action. The SWOT analysis offers precise data and cutting-edge analysis that is necessary to create a perfect strategic plan and outline the direction for a significant industrial robot deployment in FPI. The SWOT analysis is a 2X2 matrix, each field is obtained by segmenting the components into their sources (internal and external) and the type of their impacts (positive and negative). The opportunity and threat are external elements since they are uncontrollable and not part of the studied region, whereas the strength and weaknesses are internal factors because they are controllable and came from that area (such as environmental, legal, socio-economic etc.). The widespread use, interpretive flexibility, and relative simplicity of the SWOT analysis can be attributed to its popularity. It is a method that aids in limiting and organizing information, provides a thorough understanding of the problem, and makes decision-making easier [23].

Table 1: The SWOT analysis of industrial robots in FPI

	Positive factor	**Negative factor**
Internal Factor	**Strength**	**Weakness**
	• Increase productivity and efficiency • Reduces production cost and increases profitability • Decision-making ability • Flexibility and easy monitoring of processing line	• High initial investment • Required special training and skill • High maintenance and repairing cost • More dependency on computer and IT services • Cannot adapt to unexpected situations
External factor	**Opportunities**	**Threat**
	• Alternative to scarcity of manpower • Provide working environment without human intervention • Ensuring food safety • By using effective marketing strategies, it helps in flourishing the business • Expansion of IT infrastructure and digital market • Formulation of standards and regulations	• Risk of data breach • Cybersecurity issues • Threat to decrease in employment rate • Legal risk concerning external data use • Rising competition

VIII. PROS AND CONS OF INDUSTRIAL ROBOTS IN FOOD PROCESSING INDUSTRIES

The robots themselves present the initial challenges because they are complex and require maintenance. It requires skilled operators, which is lacking in current scenario. Industrial robots are expensive, challenging and with lack of versatility to use across many

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industries. Recent developments have created new opportunities for the widespread usage of industrial robots. Industrial robot uses on a large scale, however, has both benefits and drawbacks. Here, some of the most important pros and cons are addressed.

1. Advantages of extensive deployment of industrial robots

- **Ensuring food safety:** Food-borne diseases cause significant morbidity and mortality globally. It is largely attributable to contaminated food and water. Automation in the food industry can significantly reduce incidences of food-borne diseases by ensuring worker safety and a clean environment to prevent product contamination. Robotics-enabled automation can keep the processing line's hygiene up to the mark, as well as the hygiene of the robots themselves. With all food safety precautions in place, working of robots in a closed environment is also possible. With this benefit, food contamination can be considerably reduced [24].

- **Decision making ability:** The robots are fully controlled by the programmable language which is easily accessible and can mimic the human brain. The decision-making abilities acquired by artificial intelligence can fix the issue if the rapid change happens during the in-line process. They are less prone to error than human because of their precise functioning methodology. With such properties robots can minimize the damage and production losses. Robots equipped with vision systems may conduct inspections objectively with reduced human prejudice without possibility of human missing rejects.

- **Speed up the production:** A human worker can work efficiently for eight hours; over that time, this may limit the production of processed food in FPI. However, a single robot is capable of carrying out multiple jobs that require several human workers in a shorter amount of time and with superior accuracy. It keeps the supply and demand chains functioning smoothly.

- **Increased degree of automation:** The food and beverage industries are becoming more automated as a result of current changes. Traditional approaches are ineffective compared to the availability of advanced industrial and service robots for meeting the demand for personalised and intelligently packed food.

- **Reducing carbon footprint:** Every year, robots get more sophisticated. Because they use less energy during production, they lower overall energy consumption. Highly précised robots merely result in fewer rejected and inferior products. Additionally, this has a favourable effect on the ratio of resources input to output.

- **Secure supply chain:** A pandemic like COVID-19 has revealed production facilities' previously unnoticed weaknesses. Even after lifting lockdown, only 50 per cent workers were allowed to work in industries. Due to a total reliance on human labour, efficiency of the industries has been hindered and resulted as increase in the cost of essential goods.

- **Heavy and monotonous tasks:** Heavy lifting and monotonous work require a lot of strength and constant focus, yet maintaining the same level of productivity throughout

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an operation is impossible for human worker. Industrial robots can do tedious or arduous work effectively, which lowers the likelihood of accidents and insurance claims. The robots show good faith with contemporary development of collaborative robots and specialised grippers, and they prevent drudgery and keep the ability to accomplish tedious tasks.

2. Drawbacks of deployment of industrial robots

- **High initial investment:** Implementation of industrial robots comes at huge capital investment but as they are productive and never stop working, they provide a decent return on investment. However, because the FPI industry in India is so dispersed at the home, cottage, and small-scale levels, it is practically hard for smaller companies to invest a significant amount of money in buying and deploying industrial robots.
- **Scarce availability of experts:** The initial setup of industrial robots requires a lot of training and expertise for proper working ability and safety of human workers. Once installed, the industrial robots require specialised operators, regular maintenance and precise programming. Despite the fact that the number of people with this skill is growing, it is still not enough.

- **Limitation of multifunctionality:** Robots are used in industries in a great number and variety, but unlike human workers, they are programmed to execute a certain sort of task. Actuators, vision systems, and conveyor systems, which determine whether industrial robots are successfully implemented or not, can all be replaced with different one when performing specific task using industrial robots.

- **Work space safety:** The safety of the human workers is of utmost importance when working alongside an industrial robot or cobot. The risk assessment analysis is performed to assess the workspace of industrial robot, its speed, nip point, and potential risk related to EOAT in cobot.

- **Cybersecurity:** Because most industrial robots need to connect to the internet, cybersecurity is the main risk associated with their use. Therefore, great attention must be paid to robot safety in order to ensure that hackers cannot unlawfully record or control them.

- **Job loss:** Job loss is the primary objection raised against the deployment of industrial robots in FPI. Robots are seen as a threat to employment in countries with huge young populations since a large number of people from developing and underdeveloped nations migrate to other nations in quest of skilled or semi-skilled professions. The key issue at hand is how to address the likelihood of widespread unemployment brought on by the extensive usage of industrial robots.

IX. FUTURE PROSPECT OF ROBOTS IN FOOD PROCESSING INDUSTRIES

The FPI provide an enormous opportunity for the large-scale deployment of industrial robots for automated production. The recent developments in automation, computer science, and robotics are a clear and obvious indication that future enterprises will depend more on these systems. In addition to increasing competitiveness, the steadily rising use of robots in

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FPI is partially due to the fact that automation costs are now relatively lower than in the past. Numerous technical obstacles to the efficient use of industrial robots have been overcome, and their use has been demonstrated in handling multiple tasks like pick-and-place operations, packaging, palletizing, and minimal processing of fruits and vegetables. There are numerous challenges that need to be resolved, especially in the availability of skills and expertise to implement robotics, despite the fact that the technicalities of robot operation are accomplished in a number of activities. Since, automation is becoming more affordable, industrial robots can be used extensively to increase competition. Since they are taught to carry out every task precisely, the robots frequently produce finished products more while generating less waste, which aids in achieving the sustainable development goals. Robots are especially helpful in situations where gentle touch or workability is required, such as applying cake, icing or decorating food items in three dimensions, and places where labour availability is scarce. Additionally, it makes more sense to replace human labour with robots for labour-intensive, hazardous jobs and tasks that have a high likelihood of drudgery, such as lifting heavy packages or boxes, slaughtering and packing, and monotonous tasks. Robots can be used to perform tedious and hard tasks, which could result in transportation and logistics handling jobs. The manufacturing sectors are moving into the Industry 4.0 phase, where there is a great chance that robot deployment will increase significantly. Robots will be partially or totally automated in Industry 4.0, and some of them will be managed by cyber-physical systems (CPS). There was a need to create a CPS where human operators could direct robots to carry out activities because human cannot be substituted by robots in many specialised occupations. The research in this area is still in its infancy stage and much more work has to be done. Modern methods like virtual reality and augmented reality are being tested in small-scale manufacturing plants to interact with robots through CPS. The *ABB IRB 1400* robot is being tested with augmented reality, allowing the operator to control the action of the robots from a safe zone up to 6 metres via touch controls or gestures in mid-air. It is quite certain that robots will take fewer types of jobs away from people, but they will nevertheless increase employment in the technology sector and on the labour market.

X. CONCLUSIONS

Industrial robots were primarily used in the food industry for pick and place, packaging and palletisation operations, but have enormous potential for its applications in new emerging areas. The technological challenges for various applications are already meet by the modern-day industrial robots but still need to address the issues related with skills and expertise in implementing the automated solutions. The future of robotics in food industry is both exciting and interesting. Robots can be used in such jobs where working conditions are not suitable for human being, constant strength and consistency is desired such as animal slaughter house, where ambient temperature may go up to around 50 °C. The grippers, which comes in direct contact with food products are made up of High-grade Aluminium, nickel plated metals or stainless steel, those are easily washable with pressurised water to prevent contamination. The intervention of robots with such silent features ensures the food safety and security in production and manufacturing lines. In India, operators control the activities of the machine which cause hindrance in working of machine, if self-operated machines (Industrial robots) are used they can help in increasing the production as well as productivity. There are robots which work as a journalist, to write news; such type of robots can be used for writing reports from the stored data of processed food to maintain the records in inventory or warehouses. It is required to design and configure the robot in such a way so it can work in

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close proximity with human with high level of safety. In near future, the phrase "untouched by human hand" could well become a strategic marketing strategy to differentiate the food products in the future if the progress in this direction could have made.

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