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Robotics Intervention in Food Processing Industries: A Mini Review

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Authors' contributions

This work was carried out in collaboration between both authors. Author PK wrote the first draft of the manuscript. Author Lalita helped in article structure and drafting in manuscript preparation. Both authors read and approved the final manuscript.

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Mini-review Article

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ABSTRACT

The food manufacturing industry, that is both diversified and fragmented, plays a crucial role in economies of all the nations. This review is an approach to provide comprehensive knowledge about the status of use of robots in food processing industries. With advancement in powerful, precise and quick robots, automation has been helping in performing industrial operations rapidly. There are number of modern robotics systems employed in food industries, and they are mostly geared toward the high-volume, long workability and handling single-product line but now emphasis is given on multifunctionality of robots by developing replaceable grippers. The shortage of labours due to young people leaving their nation for better job opportunities in developed or high-income countries, and also in pandemic like situation, this had opened the doors for exploring other options for laborious tasks in important sectors like food processing industry. If robots would be used at larger extent in food processing industry at full capacity, in addition to boosting output, it has the potential to safeguard food supplies in unprecedented circumstances and beyond.

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1. INTRODUCTION

International migrant workers numbers are increase with each passing year. In 2019, total 169 million international migrant workers were recorded, which was 3 per cent higher than 2017 i.e., 164 million. Among them, around 27 per cent workers get jobs in industries of foreign nation. Other than industrial worker, 66 per cent worker engage in service sector and only 7 per cent in agriculture sector. These worker goes in other nations in search of better job opportunities and higher standard of living. The high income and upper middle-income countries are major destinations, 67 per cent and 33 per cent, respectively [1]. This leaves a void in nations growing a faster pace but not comes in above mentioned two groups of nations especially Asian countries. Also, during the covid-19 pandemic, all manufacturing hub in almost across the world were under lockdown. Due to which working of manufacturing sector has hampered significantly.

The higher number of migrants and pandemic like situation opens the new doors for use of more promising alternative solution for artificial shortage of industry workers. The industrial robots are perfect choice to fill this gap, which is leading reason behind start of era of intensive use of such robots in industries especially in fast growing countries. In past years, continuously it is observed that highest numbers of robots were being installed in Asian countries, especially in China. The number of installations in industrial robots across Asian continent in 2017, 2018 and 2019 were 0.28, 0.25 and 0.26 million units respectively, which is far higher than being installed in Europe and America [2].

The term "robot" has typically been used to refer to a manipulator that possesses several degrees of freedom and the ability to be reprogrammed through the utilisation of a high-level programming language. Robots can carry out a wide variety of jobs because they are equipped with a wide array of tools and can run the required software. The robotic arm could have anywhere from three to seven axes and be configured in either a serial or parallel fashion. Each joint can be operated by a driving system that is either electric, hydraulic or pneumatic, and easily monitored by a computer. It is possible to operate the joints of the robot using a central controller, which allows the robot to carry out a various movements. An input/output unit or a serial/parallel communication line can be used to interface the controller with other devices or systems, such as a computer vision system. One of these other devices or systems could be a computer [3].

In addition to this, the main controller supplies a method for the operator and the programmer to interface with the system [4]. Regarding food processing, it is imperative that the robotic arm, its controller, and any ancillary devices be built to endure working environment as well as the during conditions operation. While cleaning, it is common practise to make use of high-pressured hot water as well as a variety of chemical agents. The system's design ought to be comply with all the mandatory standards and regulations that apply to machinery used in food processing. Which is a prerequisite that is being taken into serious consideration by makers of robots right now. Some companies that specialise in the manufacture of robots are now selling adaptable automation systems for the food processing industry.

2. METHODOLOGY

The review and literature were collected by using the keyword in google scholar. Firstly, "robot, robotics and automation" keywords were used to collect literature and search was restricted up to year 2005. After that, the search was further narrow down to keywords "food industry", "food safety and security" followed by end-effector and/ or gripper. The most relevant papers were selected and used for current review.

3. STATUS OF INSTALLATION OF ROBOTS IN INDUSTRIES

Robots established a significant presence in various business sectors during the previous decade. According to the *world robotics-2021 (industrial robots)* published by the International Federation of Robotics [2], the number of robots that were deployed across the globe in 2010 was just 0.12 million; however, this figure has climbed to 0.38 million in 2020. Between 2014 and 2019, annual installation saw an average annual growth of 11 per cent. The number of installations had climbed to 0.42 million by the end of 2018, but in 2019 this number declined slightly due to economic disagreements between the United States and China; and decreasing

demand in robot-intensive industries, such as the automotive and electrical/ electronic industries.

The numbers shown in Fig. 1, represent the annual installation of industrial robots across the world. Total 0.38 million industrial robots were sold worldwide in 2020, with 0.26 million of the sales occurring just in Asia. Approximately 68% of all newly installed robots in 2020 were located in Asia. Because of the need to handle large pieces of machinery and do precise work, the automotive industry is the sector that makes the most use of robots. The food and beverage business are the fifth largest in organized sectors that utilises robots. Currently, approximately three per cent of all robots manufactured were intended for use in the food and beverage business.

Robots are having an increasingly significant impact on society for several reasons, the most important of which are:

- The rapid advancement of AI and related technologies
- The continued trend toward automation
- The preparation for an Industrial revolution 4.0.

South Korea, Singapore, Japan and Germany are the countries that have *robot density*, (defined as the number of robots in use per 10,000 employees) 932, 605, 390 and 371 robots, respectively in their workplaces.

3.1 Installation of Industrial Robots in Different Manufacturing Sectors

The most automatized organised sector is electronics and electricals followed by automotive sector. Currently, food and beverages sector are fifth highly automized among the organized sectors and is growing at satisfactory rate (Fig. 2). Approximately 22.45 per cent of installed robots were installed in unspecified sector. Around 5 per cent robots are utilized in plastics and chemical products, this also includes the packaging material, storage containers and food grade chemicals used in food industry. This offers a huge potential to grab the opportunity and utilized such robots in food and beverages industry.

3.2 Robotization of Food Processing Industry

The Fig. 3 indicates total number of robots installed in food and beverages industry every year and its future trend of installation of robot in sector. In 2020, around 0.12 million robots were installed in the food and beverages industry which is expected to increase to the level of 0.14 million in 2022.

In 1990s, the bakery business witnesses the very first instance of a robot being used for direct food handling. These robots could carry out straightforward operations such as holding and placing task at respectable pace of between 55 to 80 cycles per minute. At that time, industrial robots were primarily used for palletization and packaging operations. But currently around 40 per cent of industrial robots are utilized in palletization and 26 per cent in packaging line of food and beverages. Although meat, fish, and poultry make up a sizeable amount of the food that is consumed worldwide, the production of these foods does not lend itself very well to the use of mechanised processes. The diversity and adaptability of the products, as well as concerns over hygiene, quality, and the safety of the consumer, as well as increasing challenges associated with the manual processes involved in food production, are the primary causes of the issues.

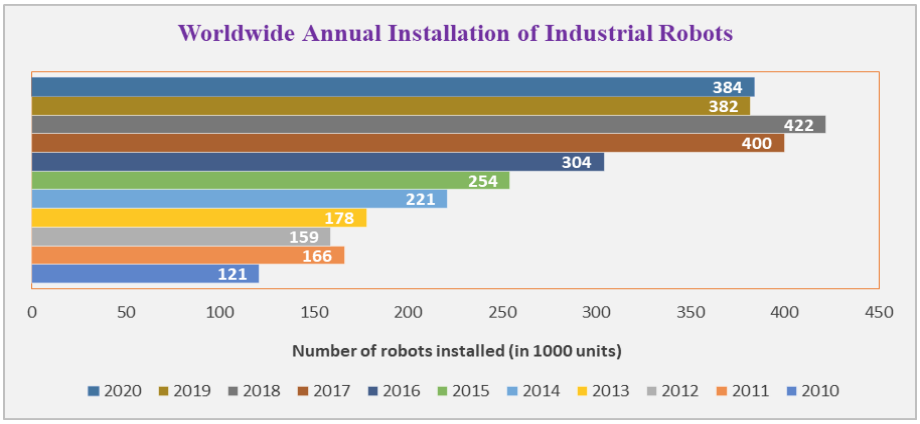

Fig. 1. Worldwide annual installation of industrial robots, 2010-20 [2]

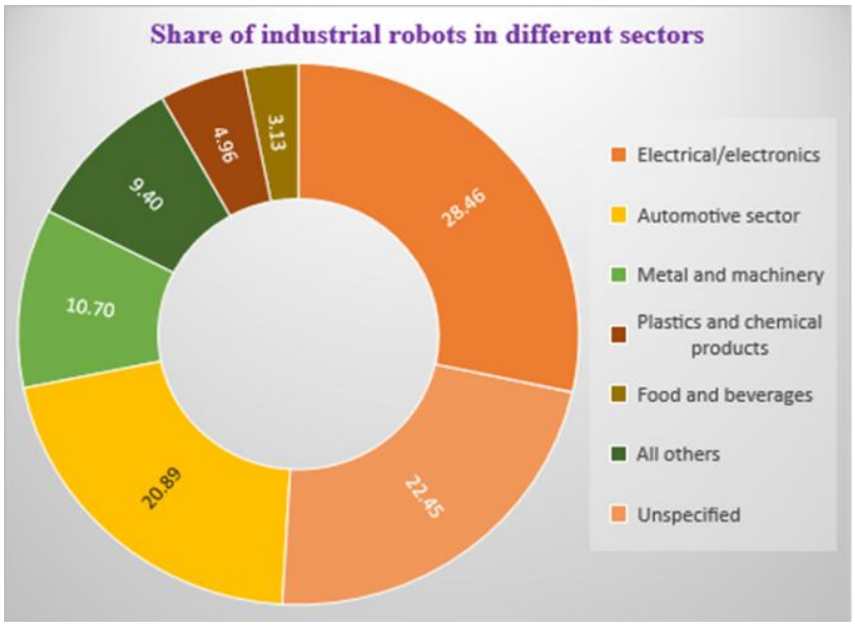

Fig. 2. Share of robots in different sectors across the world in 2020 [2]

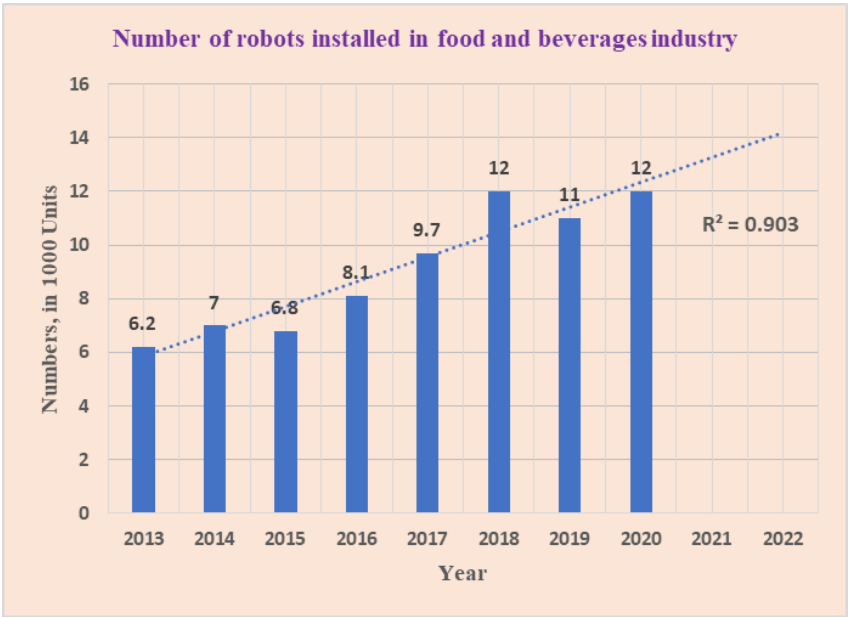

Fig. 3. Worldwide number of robots installed in food and beverages industry in 2020 [2]

It is desirable to explore the possibilities in advancement in robotic science because its influences are encouraging the growth of robotics and automation in meat production facilities. This eliminates the possibility of human contact with the product and, more importantly, removes workers from potentially hazardous working conditions. In this industry, the use of robots is prevalent for a number of objectively beneficial reasons, including higher productivity, improved production control, and output uniformity.

4. APPLICATIONS OF ROBOTS IN FOOD SECTOR

4.1 Operation wise use of Industrial Robots

4.1.1 Primary processing industry

Several businesses are engaged in the automatic grading of fruits and vegetables. 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 for fruit grading [5]. This fruit-grading robot can evaluate 9000 fruits each hour and can capture photographs of the top, bottom and sides of each fruit in 4.5 seconds per cycle. Based on Bernoulli's principle, grippers are developed in the series to handling delicately sliced fruits and vegetables [6]. The gripper enables the contactless or minimum contact lifting of the objects to minimising risk of contamination and damage to delicate fruits. Surface moisture can also be removed using the airflow created by the robot over the object.

4.1.2 Packaging and handling

Even though robots have long been used in various aspects of the food supply chain, they have lately improved to the point where they can fully automate the packaging process [7]. This entails a switch to robotics for all facility's traditional contact points, including depalletizing, unpacking, and primary, secondary, and tertiary packaging. In reality, compared to humans, robots can carry out their tasks with higher accuracy and precision and in less time. These kinds of mechanic robots are utilized in storage, godowns and supermarkets. Also, autonomous guided vehicles that can carry items on their top, tow objects behind them in trailers, or both are employed in warehouses. Such robots have navigation systems so they may complete their tasks efficiently, quickly, and precisely without running into other robots or getting into the way of their work. Because mobile robots have trouble reacting to unanticipated disturbance, they are typically deployed in highly regulated situations like production lines. A selected handful of these vehicles also have grippers to hold the stuff as given in Table 1. Universal gripper is also being developed that be may be used for a various object, independent of their shapes [8]. It can also be helpful in a number of food processing applications.

4.1.3 Quality control

In quality control, this is very clear that robot should be provided with capability to see i.e., Machine vision system [15]. For instance, inspecting incoming materials during filling process was historically performed manually. However, with robots, this role can be managed automatically in-line, with bottles being examined as they are filled. It includes handling unpackaged food items like cheese, meat, and poultry as well as bottles, trays, cartons, and other containers for food and drink.

4.2 Industry-wise Use of Industrial Robot

4.2.1 Bakery industry

In bakery industry, the 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 contain "Dual check safety" (DCS) software, which keeps them in the right position, in relation to the conveyor's speed and biscuits' orientation. Because they require less maintenance and have a longer lifespan (>1 million cycles), magnetic grippers are used to handle baking tins that have reached temperatures higher than 1200 °C. Robots are employed in cake production lines for icing, decoration, and slicing. A camera equipped with a computer vision system is available to create a three-dimensional (3D) map of the cake's surface, which may then be used by the computer to determine the robot's tracking path when applying frosting or icing. The accurate adjustment of distance between the “Icing gun” and the cake’s surface by the robots prevents deformation of cake. Robots are equipped with an ultrasonic knife installed on a multi-axis robotic arm that can provide a complex motion profile to cut many things at once while synchronising with the conveyor's speed on pastry production line. 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.

4.2.2 Meat processing industries

Meat and its allied sector of food industry is one of the major sectors which required to minimize human intervention and improving automation to reduce human drudgery and creates a hygiene working environment. Studies reveal that meat packing is one of the riskiest tasks in the meat processing industry, and carcases must be handled to preserve the best quality of meat texture and dimensions along with human operator’s safety. Robots have been developed to respond to the different characteristics of animal carcasses using sensors, meticulously determining each carcass's proportions before putting it. Due to the removal of human workers from this dangerous and tedious operation, the

Table 1. Grippers used in picking and handling of food produces

Principle	Material shape	Food product	Description	Authors
Bernoulli Effect	Flat, round, irregular	Tomato, cookies, strawberry, grapes, Marshmallow, Chicken nugget,	Can lift food weighing 2 g to 59 g. Required air flow increases with decrease in diameter of food. Irregular food needed >100 l/min	Sam and Nefti. [9]
Bernoulli effect	Flat and round	Sugar grain, grape, strawberry, mushroom, plum and apple	The air flow rate (l/min) is directly proportional to the size of the product handled. Ranged between 167 l/min for sugar and 283 l/min for apple.	Petterson et al. [10]
Coanda effect	Flat and round	Apple, oranges, and aluminium bar	The gap between gripper and product should be minimized or tends to zero for complete prevention of air leakage.	Natarajan et al. [11]
Vacuum force	Complex shape (flat, curved, uneven and grooved)	Intimated artificial samples used.	Gripper based on Octopus sucker. The liquid membrane improved the gripping force compared with dry surfaces.	Tomokazu et al. [12]
Vacuum effect	Irregular	Meat	Gripper with 6 degrees of freedom and capable of handling flexible or deformable products.	Jorgensen et al. [13]
Vacuum effect	All shapes	Packed food like red beans.	The gripper consisted of four fingers and vacuum cups fitted to distal end of fingers. This makes them theoretically all kind of food materials and shapes.	Wang et al. [14]

robot can now chop meat accurately, quickly and more precisely.

There is a need for automation of carcase splitting because splitting requires a lot of force, and a human operator cannot continue to operate at the same pace and accuracy for an extended period. For the first time ever in meat processing, an automation system was used for carcase splitting using a robotic cell for cutting ham bones and quartering cattle carcasses [16]. Processing of meat requires repetitious and physically exhausting operation and maintaining hygiene as well as quality control. This kind of robotic cell has a vision system that determines the cutting path, and force control sensors are used to keep the cutting blade's distance from the spinal cord constant [17]. A vision system is built into the robotic arm, which is also intended to cut hocks from carcasses.

The cutting tool is immersed in a hot water tank for sanitization following each cycle of splitting. These types of robots can pick up stunned chicken from a conveyor belt, determine the bird's centre of gravity and position it in relation to the robot and shackle it when handling stunned poultry. This optical system can also tell if a bird is lying with its breast up or down.

5. ROBOTICS ASPECTS IN THE FOOD PROCESSING INDUSTRY

5.1 Ensuring Food Safety and Preventing Contamination

Food-borne illnesses, which have a high morbidity and mortality rate due to tainted food and water, are posing significant problem around the world. Automation in the food industry can significantly reduce it by using methods like sanitation and controlled working conditions to prevent product contamination. Robotics-enabled automation can keep the processing line's hygiene up to the par, as well as the hygiene of the robots themselves. With all food safety precautions, working in a closed environment is also possible for robots. With this benefit, food contamination can be considerably reduced [18].

5.2 Decision-making Capacity

The programmable language, which is simple to learn and can imitate the human brain, is used to operate the robots. Robots' decisions making ability could fix the issue if the rapid change happened during an in-line process. Robots are less prone to error than humans because of their precise functioning methods. Robots with such properties can reduce damaged produce and losses in production.

5.3 Increase the Production Rate

A single person may work continuously for 8 hours; over the time, this may limit the output of processed foods. A single robot can, however, do several activities that would take multiple people to complete with more accuracy and quickly than a human. Which helps in keeping the supply and demand chains moving smoothly.

5.4 Increased Automation

As a result of recent trends, the food and beverage industries are becoming increasingly mechanised. Traditional methods are ineffective in meeting the need for customised and intelligently packaged food when compared to the availability of advanced industrial and service robots.

5.5 Reducing Carbon Footprint

To curtail down the carbon footprint, more sophisticated robots are being made, which require less energy to operate and consequently, overall energy consumption on production lines reduces. Higher precision merely results in fewer unwanted rejection and prevent production of inferior products. Additionally, this has a favourable effect on the ratio of resources input to output.

5.6 Secure Supply Chain

The Covid-19 has exposed the industrial facilities' hidden flaws. Around 50 per cent of the workforce was still not permitted to work in industries after the lockdown lifted in many manufacturing hubs and complete reliance on human labour, the industrial productivity had impeded.

5.7 Heavy and Tedious Tasks

The robots demonstrate their good faith with the modern development of collaborative robots and specialised grippers in order to avoid the drudgery and keep the ability to complete the boring activity.

6. DISCUSSION

The primary obstacle is that such robots cannot yet be used in the jobs that are currently being

carried out by the skilled labour force. Innovative end-effectors and sensors are required so that manufacturers can meet the challenges posed by a wide variety of jobs, as well as variations in the form, size, and characteristics of the goods. The complex or highly skilled tasks may be automated by combination of these technologies and the implementation of intelligent robots with improved learning capacity. It will be necessary to construct robots with a higher level of intelligence to automate the myriad of chores that we perform without much thought. A significant part is played by the decision regarding the end effector (grippers, cutting tools, etc.) as well as the capabilities of the sensing technology, along with the software and control techniques for the manipulator, when it comes to the items that have a greater variety. The foremost thing needs to ensure is that robots must be designed in such a way that they can be set up to work in proximity of manual operation workers while maintaining a high level of safety. Although the integration has the potential to result in workable solutions in practically every circumstance, its applications in food processing have not yet been fully explored.

7. CONCLUSIONS AND FUTURE PROSPECT

Although new applications of robots are emerging, but in food industry till now they were being used largely for packaging and palletization tasks. The development of new robots and their utilization in the food business in near future is getting both interesting and exciting. At once, these robots cannot be employed as alternative for all the operation in industries. Whereas they can be employed in specialized operations such as hazardous, repetitive, and laborious tasks to avoid exposure of human worker to such kind of tasks. But special emphasis needs to be given on development of multi-functionality gripper made from food grade materials such as high-grade aluminium, nickel-plated metals, or food grade stainless steel. As, these materials are easy to clean with high pressure water and prevent contamination while handling food products. Robotic intervention with such silent features makes sure the safety and security of the food product being processed. By keeping all factor in mind, we can assume that “self-operated machines” (Robots) can aid in boosting production and productivity in the food processing industries.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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