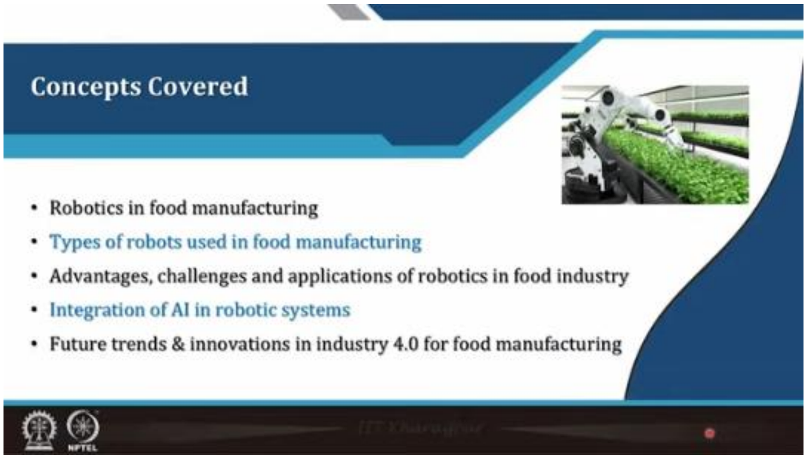
FOOD SCIENCE AND TECHNOLOGY

Lecture55

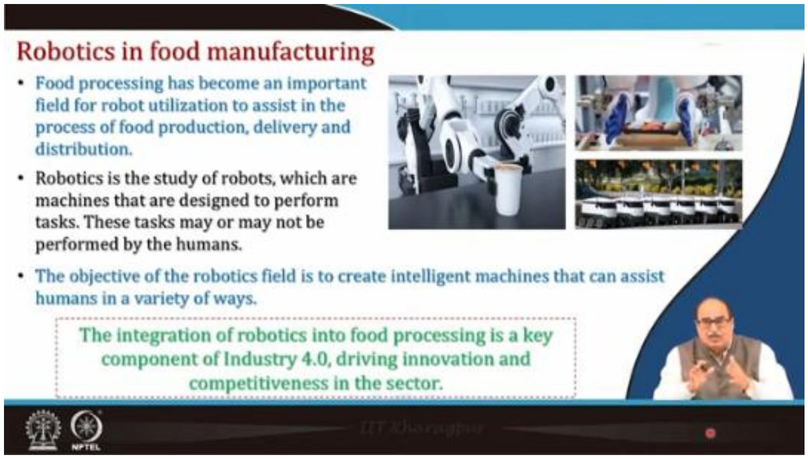
Lecture 55: Robotics and Future Trends in Food Manufacturing

Hello everyone. Namaste. Now, we are in the last lecture of the eleventh module.

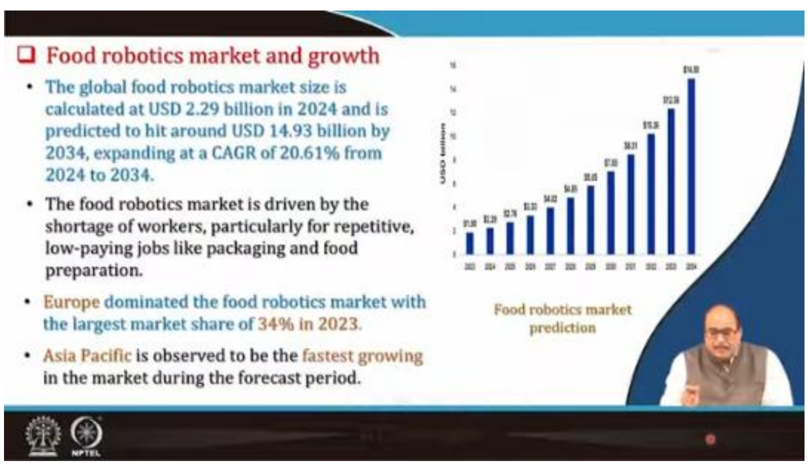
So, in this class, in the next half an hour or so, we will talk about robotics and future trends in food manufacturing.



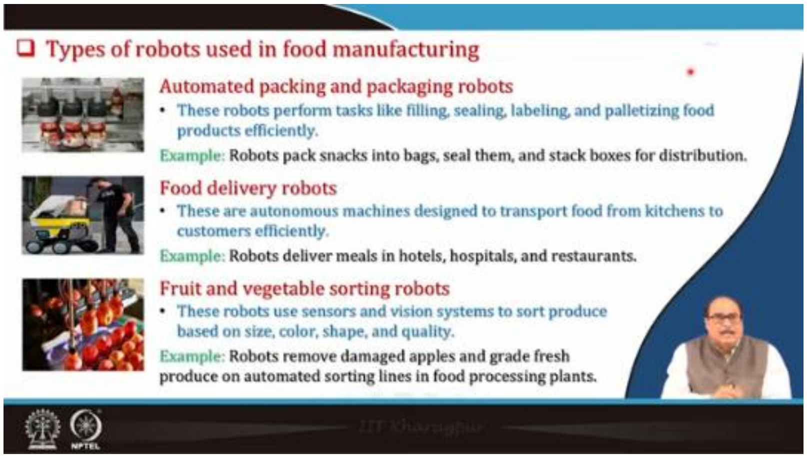
We will discuss robotics in food manufacturing, its applications, types of robots used in food manufacturing, advantages, challenges, and applications of robotics in the food industry and the integration of artificial intelligence in robotic systems. Finally, we will talk a little bit about future trends and innovations in Industry 4.0 for food manufacturing.



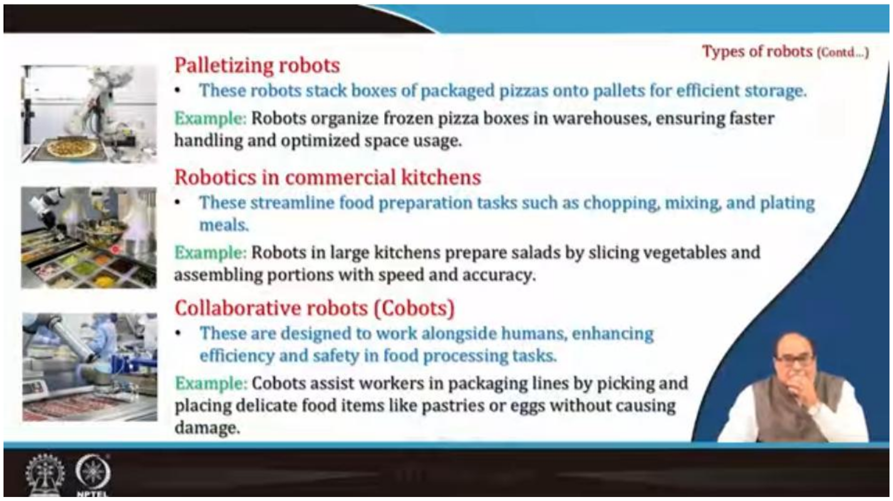
So, what is robotics? And you know that food processing has become an important field for robot utilisation to assist various operations in the value chain. For example, in the process of food production, even its delivery, packaging, distribution, and so on. So, robotics is basically the study of robots. These are machines that are designed to perform tasks. These tasks, which are performed by robots, may or may not be performed by humans. The objective of the robotics field is to create intelligent machines that can assist humans in a variety of ways. So, the integration of robotics into food processing is a key component of Industry 4.0, which drives innovation and competitiveness in the food sector.



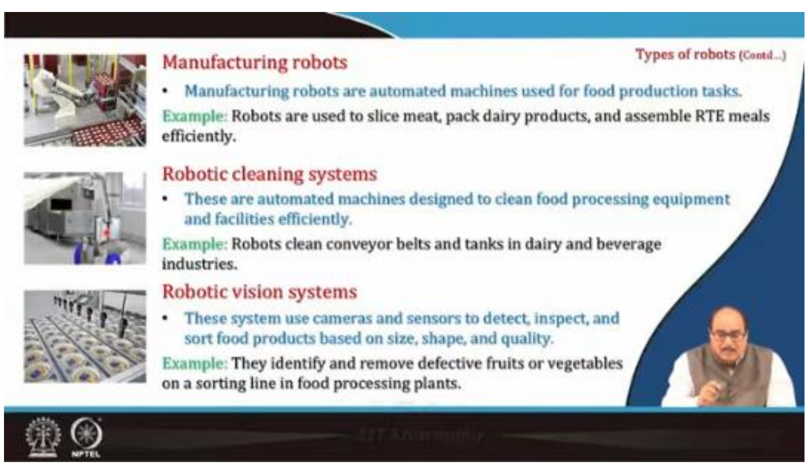
If you look at the food robotics market and its growth, as you can see here in this figure, in the year 2024, the global food robotics market is calculated at $2.29 billion, that is 2.29 billion US dollars. And it is likely to grow to US$14.93 billion by the year 2034, and therefore, the expected growth rate, that is CAGR, is 20.61%. That is from the year 2024 to the year 2034. So, in the next 10 years, you can say that it is growing at a much higher rate than any other sector, even in the food processing sector or other sectors. So, the food robotics market is the industry's future; it is growing at a very high rate. The food robotics market is driven by the shortage of workers. Particularly, for repetitive and low-paying jobs like packaging and food preparation, even handling, serving, etc. If you look at the global scenario, you will find that Europe dominated the food robotics market with the largest share of 34 per cent in the year 2023. Asia Pacific is observed to be the fastest-growing market during the forecast period.



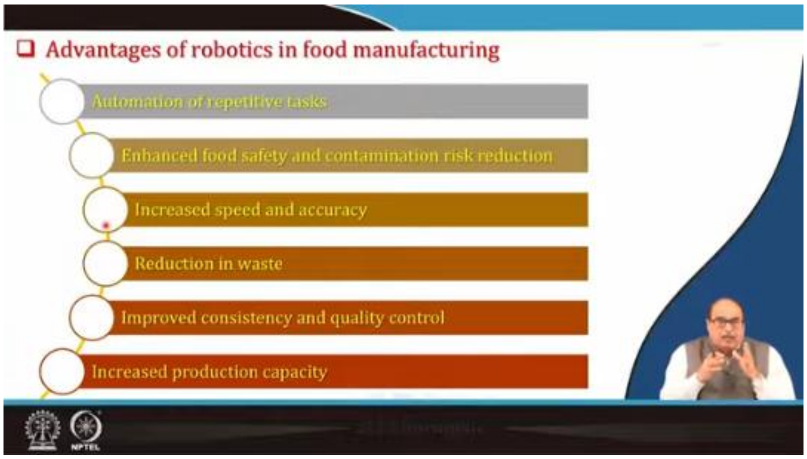
So, what are the different types of robots that can be used or that are being used presently in food processing or in food manufacturing? So, one is the automated packing and packaging robots, and these robots perform tasks like sealing, labelling, palletising the food product efficiently without any problem, without much loss, without much broken, etc. For example, robots pack snacks into bags, seal them and stack these boxes for distribution. You can see here in the figure what the work is being done by the robot. Then there are food delivery robots. These are autonomous machines. which are designed to transport food from the kitchen to customers efficiently. That is, robots deliver meals in hotels, in hospitals, in restaurants, etc. Then, the fruits and vegetables sorting robots use sensors and a vision system to sort produce based on their size, colour, shape, quality, etc. Like robots are now, they are effectively used in the fruits and vegetable processing industry to remove damaged fruits, such as damaged apples or grade fresh produce or in automated sorting lines in the food processing plants.



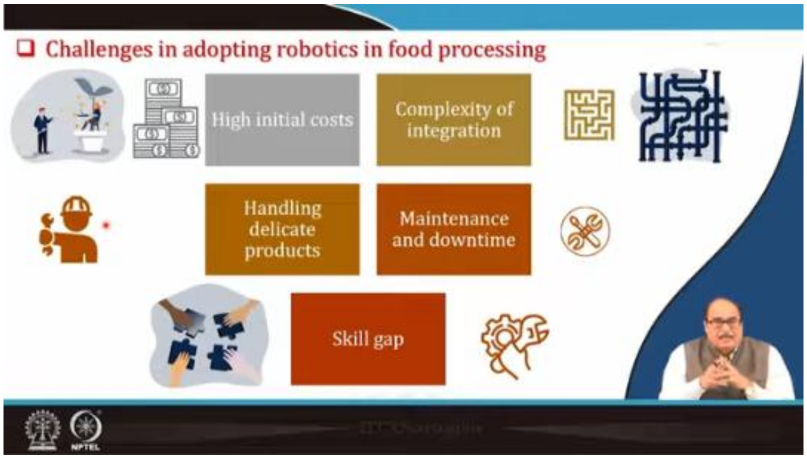
For example, pelletising robots stack boxes of packaged pizzas onto pellets for efficient storage. Robots organise the frozen pizza boxes in the warehouse, ensuring faster handling and optimising space usage. So, this is one example. So, similarly, there are many in the food industry, many of which involve pelletizing, etc., that can be effectively done by these robots. The use of robotics in commercial kitchens. These robots can streamline food preparation tasks such as chopping, mixing, and plating meals. The robots in a large kitchen prepare salads by slicing vegetables and assembling portions with speed and accuracy. Then, collaborative robots, which are popularly known as cobots, are designed to work alongside humans, enhancing efficiency and safety in food processing tasks. For example, cobots assist workers in packaging lines by picking and placing delicate items like pastries or eggs without causing any damage. However, even if you use humans, there may be some eggs that may be broken, or the pastries, particularly the filling, etc., may be damaged, and the designs may be destroyed. But here, once they are set, robots are given the signal that they are given guidance, and they will do the job precisely without any problem.



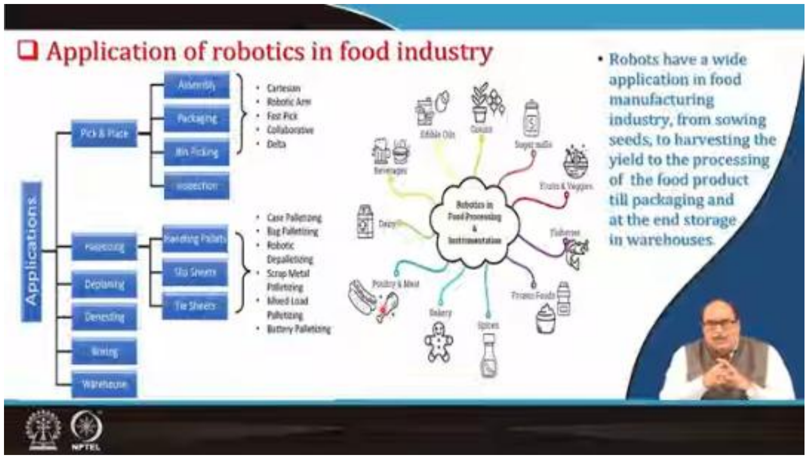
Then, there are manufacturing robots, which are automated machines that are used in the food production line. Like robots are used to slice meat, pack dairy products, assemble ready-to-eat meals, etc., efficiently. The robotic clinic system is again a very important use. These are automated machines designed to clean food processing equipment and facilities more efficiently, eliminating human errors in this process. Robots clean conveyors, belts, and tanks in the dairy and beverage manufacturing and food processing industries. Then, robotic vision systems. These systems use cameras and sensors to detect, inspect and sort food products based on size, shape and quality. They identify and remove defective fruits and vegetables or defective batches of the production or product, etc., on a sorting line in a food processing plant and so on.



So, in this robotics, there are a lot of advantages associated with the use of robotics in food manufacturing, like obviously, it gives automation of repetitive tasks more efficiently, and it results in enhanced food safety and reduces the risk of contamination or the risk of contamination. It results in increased speed and accuracy. It results in a reduction in food wastage by improving the efficiency and precision. It results in improved consistency and quality control. And finally, and more importantly, it results in increased production capacity, and therefore, in the long run, it can affect the process of economics properly. So, the challenges are like those of any other system.



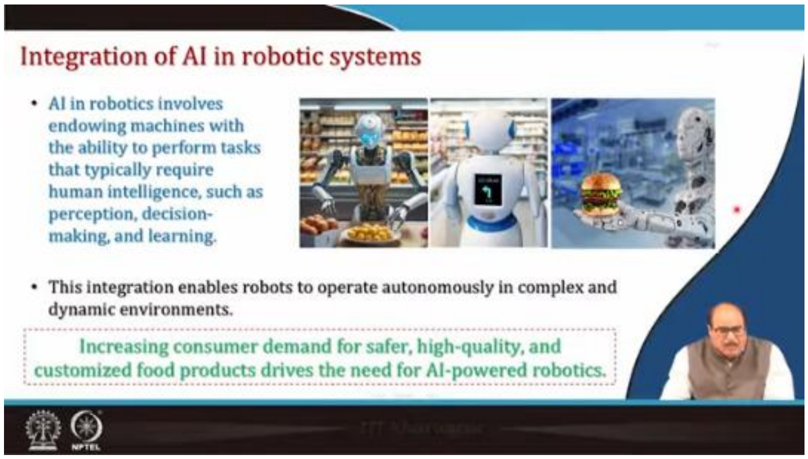
Here also, there are certain challenges in adapting robotics in food processing, and they may include, obviously, high initial capital cost, that is, the initial establishment of robotics in the plant, etc. It may require a little more capital investment. However, in the long run, it may be an economically viable process. Even the complexity of integration, that is, the integration of the robot with the various process operations with the varying raw material characteristics, etc., and all those process variables, material variables in the systems, etc. So, that becomes a little bit because of the foods, etc. There may be a portion of liquid food, solid food, paste, and all those things have varying characteristics. So, integrating this system into the robots is a complex challenge. Then, handling delicate products, again a there are many times foods you want that are particularly, you can say 3D printed foods or other such foods where the precise nutrition, etc., their exact structure is formed. So, that should be handled very carefully, even perishable foods or items that are fragile, etc. So, it becomes a mix, and the challenge is developing a robot that can suitably handle the delicate products. Then obviously, maintenance and downtime are a part of any machine. So, if it is not properly maintained, there will be low downtime, and that may be a common challenge; this should always be considered. to be kept in order and properly maintained. And then, more particularly, at present, we are facing a skill gap, although in the future it may improve; that is, there is a skill gap, and we do not have much more trained manpower who can effectively and efficiently manage these robots. So, that is a huge system; very skilled, trained manpower is needed. So, we are optimistic that in the future it will definitely it will pick up.



So, application of robotics in food industry if you look at, they have a wide application in food manufacturing industry from in fact, in the production field, in the agriculture for the sowing of the seed is planting and then in the harvesting after post harvesting in the postharvest operations in the manufacturing in the industry even processing of the food products. Even till it all the operations till it reaches to the packaging line and finally, packaging and then warehousing, transportation, storage etcetera and it can be used in almost all food processing sectors like in the beverage sector, edible oil sector, grain, sugar mill, fruits and vegetable, fisheries, spices, bakery products, poultry, meat, dairy. So, whatever materials are there, the robot has applications and the major areas you can see it has been used in are assembly, packaging, bin packing, inspection, etc. And there are various systems like Cartesian, robotic arm, fish pack and collaborative robot and all these things can be used even then in the palletising, like handling pallets, slip pill sheets, tie sheets, etc., and then deplaning, dynasting, boxing, warehousing. So, all the operations that come to mind in the food processing industry, food manufacturing, processing, and supply chain, robots can be applied.

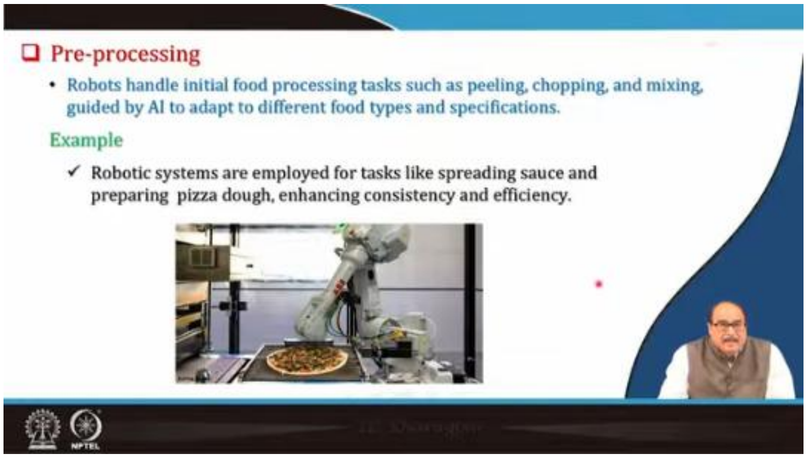
So, there are typical robotics technology applications like robot-assisted handling of raw and processed foods to ensure hygiene and efficiency in food handling. AI-driven vision systems are used for enhanced object recognition and adaptability, and these two food trays can be utilised effectively in food handling, meat processing, and delivery reports, and are used in packaging. The automation of cutting, deboning, and packaging meat products to enhance safety and consistency, where there are many more chances, if humans are involved when they handle these, but there may be a chance of contamination, etc.. Still, robotics can do its job very precisely here. In meat processing, high precision laser cutting can reduce waste and enhance safety. Autonomous robots are used for last-mile delivery, ensuring timely and contactless delivery. These robots can efficiently analyse real-time traffic and weather for optimised delivery routes. High-speed robots are used for product packing, reducing labour costs and improving output. These robots use smart sensors for adaptive packaging of diverse product sizes and shapes. So, these are, you can say, the standard robotic technologies.

Regarding non-conventional robotics technology applications, it can be used in cleaning, precision dosing, kneading, cutting, etc. For example, self-cleaning and self-sanitising technologies are used for continuous hygiene maintenance. They are AI-driven adaptive dosing for ingredient quality, batch size challenges, etc. Adaptive kneading in the bakery industry or other industries—these robots adjust pressure and timing based on dough texture, and you can very carefully regulate the dough consistency and texture to meet the bakery line requirements, etc., conveying and all those things. Then there may be laser-guided precision cutting, which reduces material waste and improves consistency. These robots can do real-time—that is, the real-time sensors provided in the robot adjust mixing intensity for optimal ingredient blending, etc., and blending of the correct, even exact formulation and very precisely correct blending—all those things. AI algorithms are used for creative experimentation with new flavours and presentation, etc., or even multi-nozzle 3D printers with robotics and AI can create complex and nutritionally optimised foods in less time with better precision. So, modern robots, everyday robots, non-conventional robots, etc., are being used; they can be used in many food process operations.

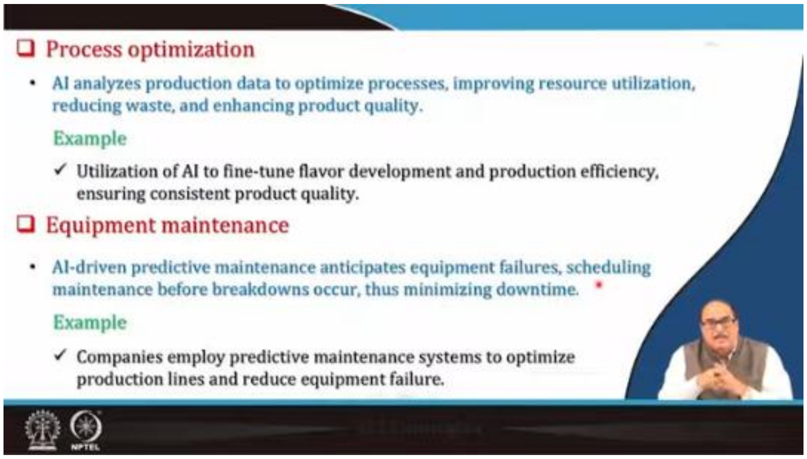


Now, integrating AI into robotic systems is essential because it gives machines the ability to do so. It has the ability that once the robot is integrated with AI, the machine will have the ability to perform tasks that typically require human intelligence, such as even perception, decision making and learning. Everything can be done with the help of the integration of artificial intelligence in robotic systems. And this integration enables robots to operate autonomously in complex and dynamic environments. And obviously, increasing consumer demand for safer, high-quality, and customised food products drives the need for AI-powered robots. So that the robot can do the job efficiently, even if they have the capability or capacity to make decisions as needed.

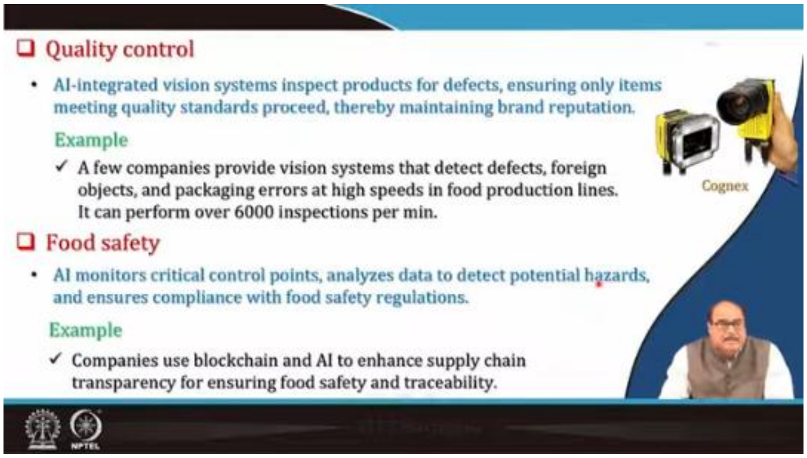
So, let us see, for example, the AI incorporated robotics, which can be used for sorting and grading. So, AI-based sorting and grading systems that use computer vision. Machine learning and sensor technologies to automate the classification of food products based on parameters like size, colour, shape, ripeness or even defects they can be used to search for defective items or good items, etc. Then, robotic systems equipped with advanced vision technology revolutionise food sorting and grading processes, for example, the detection of the best quality of carrots based on colour and shape. You can see here that there are different colours, different shapes, etc., that is, they can be taken as defective and here is the normal. Then measurement of appropriate levels of drink inside the bottle, whether the bottle is there, the drink is the quantity, its quality, what the various nutrients are, etc., that can be adequately measured here. Many companies are now using AI-driven optical sorters to remove foreign materials and defective products. From the material online, it is supposed that some production batches are defective due to some error, etc., in the process. If a particular batch is defective, it is. So, these AI-driven optical sorters can be used to discard defective lots, which obviously enhances the product quality.



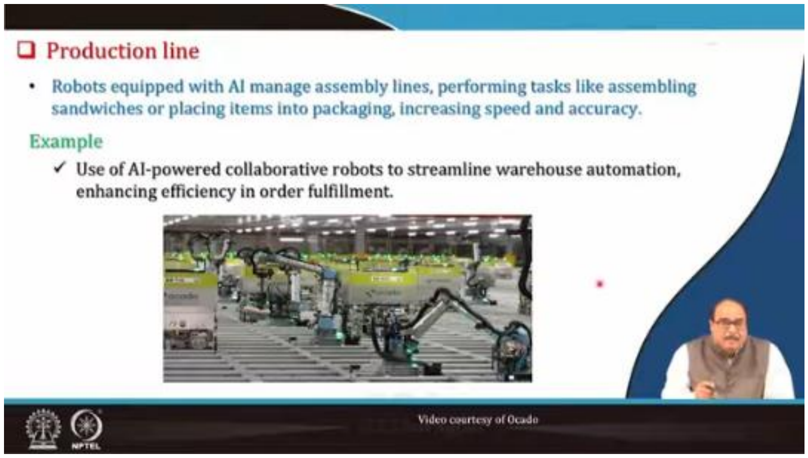
Then, AI is integrated into robots, which are used for pre-processing; these robots handle initial food processing tasks such as peeling, chopping, and mixing, guided by AI, to adapt to different food types and specifications. Some fruit may be hard, some may be soft, and some may be smooth. So, that is when you have introduced AI into the robotic system. So, they can decide whether they can, depending on their material. Then, like robotic systems are employed for tasks such as spreading sauce and preparing pizza dough, enhancing consistency and efficiency, you can say that this avoids human errors, etc.



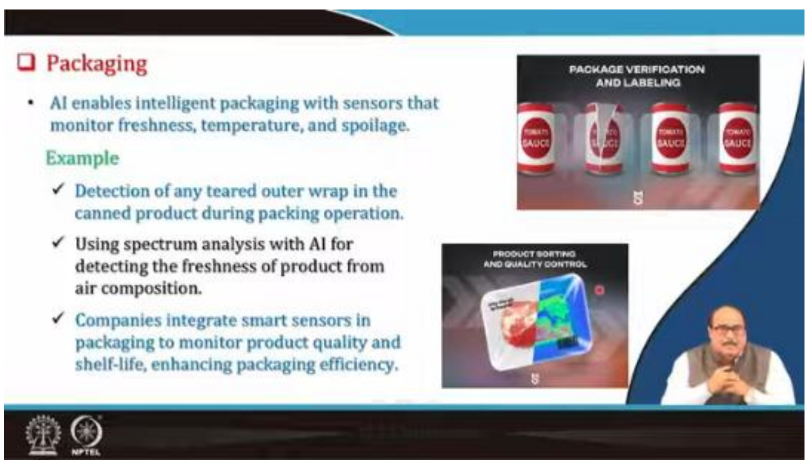
Then, this AI integration for the robots is used in process optimisation, where AI analyses production data to optimise processes, improving resource utilisation, reducing waste, and enhancing product quality. So, the utilisation of, for example, AI to fine-tune flavour development and production efficiency ensures consistent product quality. Then, in the equipment maintenance, AI-driven productive maintenance anticipates equipment failures. Scheduling maintenance before a breakdown occurs and thus minimising the downtime. For example, a few companies employ a productive maintenance system to optimise production lines and reduce equipment failure. Then, in quality control, AI-integrated vision systems inspect products for defects, ensuring only items meet quality standards, proceed in the process, and therefore, maintain the brand's reputation.



There are various systems that many companies provide, including vision systems that detect defects, foreign objects, packaging errors, etc., at high speed in the food production line, and there are systems that can perform over 6000 inspections per minute. So, they are highly efficient, highly modern and fast systems. Then, in food safety, AI monitors critical control points, such as hazard analysis in the GMP, etc. This AI can be integrated to monitor essential points of control, analyse data to prevent potential hazards, and ensure compliance with food safety regulations. For example, a few companies use blockchain and AI to enhance supply chain transparency, ensuring food safety and traceability.

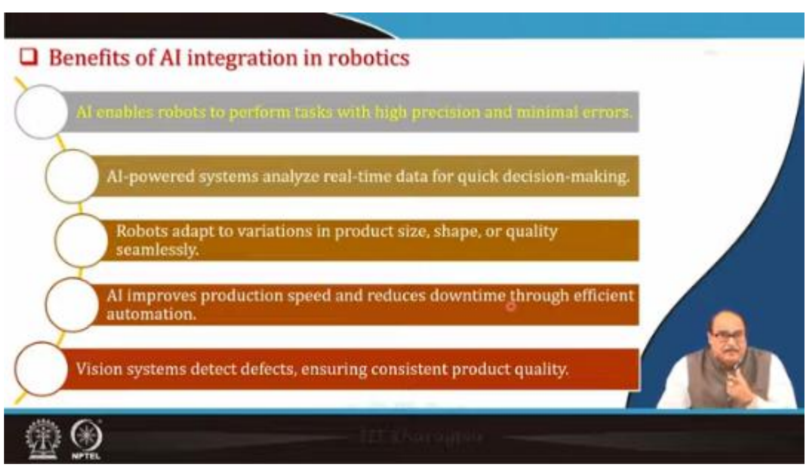


In the production line, robots with AI manage assembly lines, performing tasks like assembling, sandwiching, or placing items into packaging, increasing speed and accuracy. For example, you can see there are uses of AI-powered collaborative robots, as you can see here in this video, to streamline warehouse automation, enhancing efficiency in order fulfilment. So, these can even be used in the production line to automate processes.

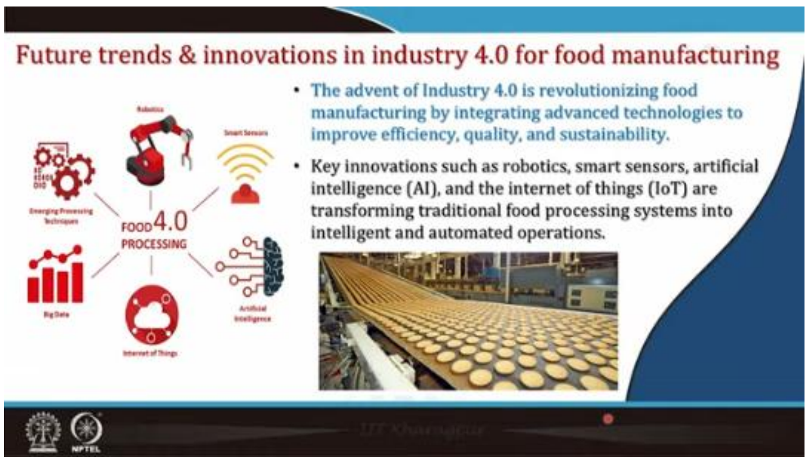


Then, in the packaging, AI enables intelligent packaging with sensors that monitor freshness, temperature, and spoilage. For example, these systems can detect torn outer wraps in the canned product during packing operations. Spectrum analysis with AI is used to detect the freshness of the product from the air composition. A few companies integrate smart sensors in packaging to monitor product quality. Shelf life enhances packaging efficiency. For example, intelligent packaging systems have various sensors or controllers, and even smart sensors can be used to monitor the conditions inside the package.

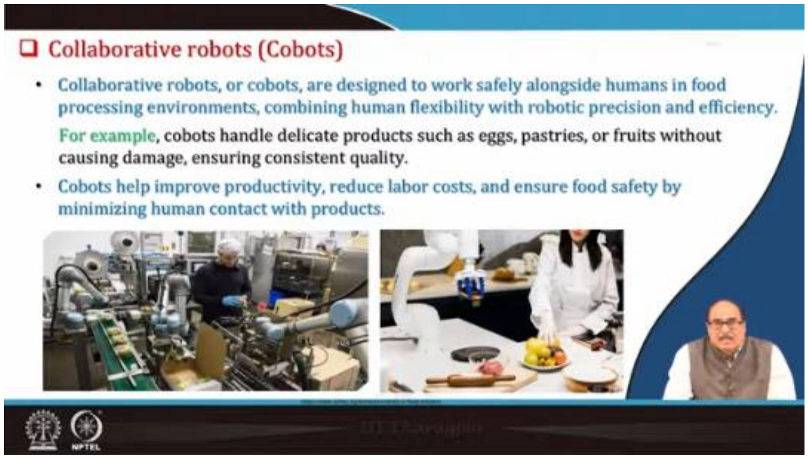
Then, let us talk about AI-based vision systems in food processing. These systems automate the inspection processes by detecting defects, contaminants, and irregularities in food products. And therefore, they ensure adherence to quality standards and reduce the reliance on manual labour. The AI vision systems can detect the presence of, for example, a spoon. There are many spoons in the packaging of ready-to-eat food, and the food they put into them. That is a spoon. So, if it is not put into the AI systems by mistake, they can inspect whether the spoon is inside the package or not or if it is an even AI system, the vision passes the vision system, they can detect. If there were any mistakes in the earlier stages, the spoon could not be placed in some packets, and the systems could easily detect this. Then, this AI system can tell whether the presence of the spoon in the product is present and at what level, if it is not good, and so on.



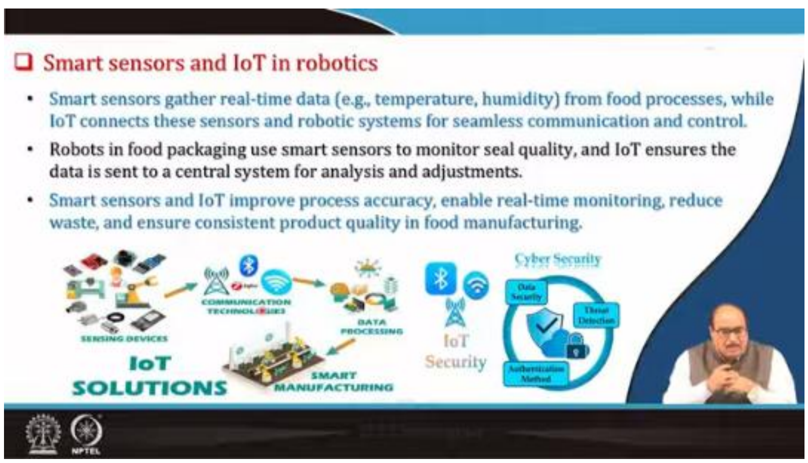
Then the benefits of an AI integration in robotics are that AI enables robots to perform tasks with high precision and with minimal errors, or even you can perfectly if you design the robots, give them proper training, you can assume that there will be no error. AI-powered systems analyse real-time data for quick decision-making. Robots adapt to product size, shape or quality variations seamlessly, giving better, more consistent output. AI improves production speed and reduces downtime through efficient automation. If there is better automation, then you can get almost no downtime, and you will get better efficiency. Then, vision systems can be placed under AI control to detect defects. Therefore, to ensure consistent product quality within the same batch or among different batches, you can get a consistently good product of the same quality.



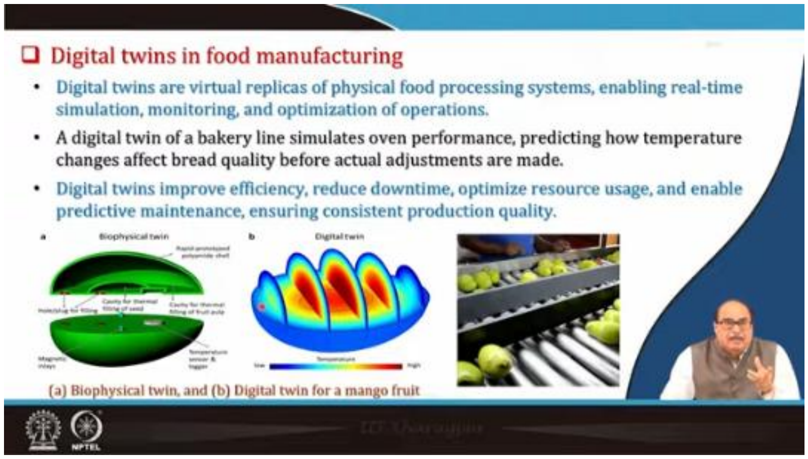
Then talk about future trends and innovations in food industry 4.0 for food manufacturing and in the earlier class also we discussed little bit that is food industry 4.0 processing industry it uses robotics, smart sensors, artificial intelligence, internet of things, big data and emerging technologies etcetera these are the future of the food processing. Particularly, food processing 4.0. Now, we are talking about the food industry 5.0. So, the advent of Industry 4.0 is revolutionising food manufacturing by integrating advanced technologies to improve efficiency, quality and sustainability. Key innovations such as robotics, smart sensors, artificial intelligence and internet of things are transforming traditional food processing systems into intelligent and automated operations.



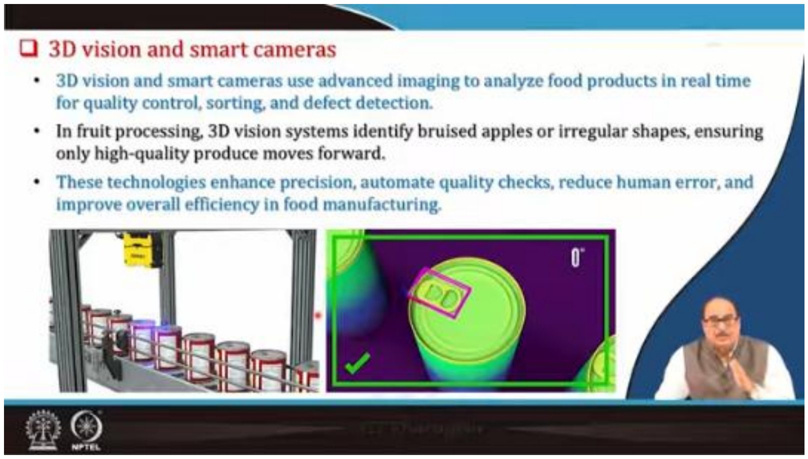
And in this case, collaborative robots are the one significant development. These collaborative robots, or cobots, are designed to work. Safely alongside humans in a food processing environment, combining human flexibility with robotic precision and efficiency. For example, cobots handle delicate products, such as eggs, pasties, or fruits, without causing damage and ensuring consistency in quality. Cobots help improve productivity, reduce labour costs and ensure food safety by minimising human contact with products.



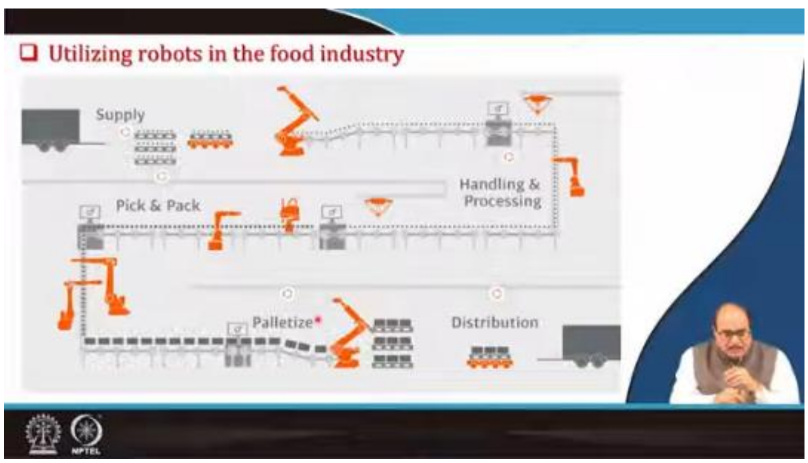
Then, smart sensors and IOT in robots. There are these sensors, smart sensors that gather real-time data like temperature, humidity, etc., from food processes. And while IOT connects these sensors and robotic systems for seamless communication and control. Food packaging or processing robots use smart sensors to monitor and seal quality. IOT ensures the data is sent to a central system for analysis and adjustment. So, smart sensors and IOT improve process accuracy, enable real-time monitoring, reduce waste and ensure consistent product quality in food manufacturing.



Then, digital twins in food manufacturing are virtual replicas of physical food processing systems, enabling real-time simulation, monitoring and optimisation of operations. And that is, these digital twins will now be used in food processing to simulate real things in a big way. A digital train, for example, in a bakery line can simulate oven temperature, and predict how it is given. You can put this digital train to the test and see how temperature changes influence product quality before actual adjustments are made. Digital twins improve efficiency, reduce downtime, optimise resource usage, and enable predictive maintenance, ensuring consistent production quality. Here, in the example, is a picture of a biophysical twin, and then it is a digital twin for a mango fruit. Mango fruit in the production line—suppose you want. You want to see that when the mango fruit is ripe, there is almost this biophysical twin, which is made like the shape of the mango, which has a hole for plugging or for filling a cavity for thermal filling and a cavity for thermal filling of the fruit pulp. There are temperature sensors, etc., and all other magnetic and rapid control polyamide cells. So, this is the biophysical twin. So, this is in place. Here, the digital twin is that the temperature goes from low to high when these systems are in place. You can even predict the material with changing variables inside the mango or other food products. What effects is it causing here?



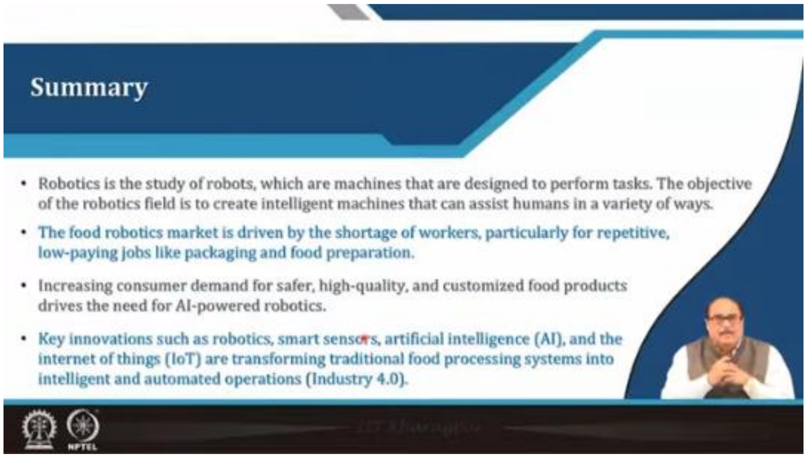
So, then 3D visions and smart cameras are again the future of food manufacturing. 3D vision and smart cameras use advanced imaging to analyse food products in real time for quality control, sorting, and defect detection. In fruit processing, for example, 3D vision systems identify bruised apples or bruised fruits with irregular shapes. Therefore, it can ensure high-quality produce which moves forward for further processing, etc. Even these technologies enhance precision, automate quality checks and reduce human errors, improving overall efficiency in food manufacturing.



This is just a schematic diagram taken from the literature that shows how robots can be utilised in the food industry, showing that it is from the supply chain and the field. It takes the raw material and then comes to the processing line, like handling and processing, where the material is handled, processed, and at every stage, robots are involved. After it is processed, the material is picked and packaged. Then, they are kept in the warehouse for storage again, their material, and then it can be further transported in the supply chain of finished goods to the consumers or the market. So, whole in the process value line here, everyone for every operation. Robots can be like this, and that is the future. It will come away; it has the potential of robotics in the future, that is, the 5D, a five industry, 5.0 industry, and 4.0 we are nowadays. It will be entirely suitable for robots to replace all humans. And this, of course, may be a bit costlier and more challenging, but still, it will result in a better-quality product and give one precise nutrition and safe products, which are good and healthy functional products.

So, there are also autonomous mobile robots, AMRs. These AMRs are self-navigating robots designed to transport materials, as you can see here. These are the ingredients or packaged products within the food processing facility, which is the large stack. These robots can be used for this; you may require several larger machines, etc. The other machines, etc., how they are being used, and what they are like, are a lot. You can see here in the figure that it is a whole lot; just by involving humans, it may be impossible or impractical. So, these robots, even a small robot AMRs, move raw ingredients like flour or packaged goods between storage and production lines in a bakery or any other industry. AMRs improve logistics, reduce manual labour, optimise workflow efficiency and ensure timely material handling in food manufacturing.

And now another very sector that is in the in the restaurant in the food supply chain and there are several companies now leading companies here I have retaken this picture from the literature from the net and which to show that as now this is the future even in the restaurants etcetera also these robots in many companies they are being used in many countries. They are taking the menu to the customers, they are taking their orders and placing it into the kitchen and then prepared food from the kitchen, they are serving to the customers as per their demands and many companies are now doing this that is the companies which are leading to restaurant automation race as these are listed here.



So, with this, I would like to summarise this lecture by saying that robotics is. The robots are machines that are designed to perform tasks. The objective of the robotics field is to create intelligent machines that can assist humans in various ways. The food robotics market is driven by the shortage of workers, particularly for repetitive, low-paying jobs like packaging and food preparation. These are the applications of robots in the future. Increasing consumer demand for safe, high-quality, and customised food products drives the need for AI-powered robots that can work precisely and intelligently. Key innovations such as robotics, smart sensors, artificial intelligence, and the Internet of Things transform traditional food processing systems into intelligent and automated operations. And that is Industry 4.0, or now it is coming with more customisation, like precise nutrition delivery, health food, functional foods, etc. So, robotics and AI have an enormous scope in the future. The future of the food processing industry and food manufacturing lies in these areas, with the hope of better-quality control, safer products, and personalised services, particularly for personalised nutrition and health.

These were the references used in preparing this lecture.

Thank you very much for your patience in listening. Thank you.