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Robots in the food industry

Application areas, opportunities and risks

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1 Introduction/topicality

The food industry is traditionally regarded as lacking in technology. Particularly following the effects of the COVID-19 pandemic, however, automation is increasingly shifting into focus in all phases of food production in terms of food safety and guaranteeing food supplies. An objectively ageing society and the labour shortage are also speeding up automation. In addition, the food chain's 'from-farm-to-fork' strategy from the production (from farm) of food to the consumer (to fork) is also becoming increasingly complex. The food industry is highly diverse and encompasses numerous industrial activities such as production, processing, packaging, distribution, preparation, preservation and gastronomy.

Industrial robots are being integrated into each link of the food chain in order to increase production, to produce a higher-quality product and to surpass customers' expectations.

For instance, robots are already being used in harvesting, but also during food transport, in food production itself or in the area of packaging. Although the extent to which robots are used in the food industry is still relatively low compared to other industrial sectors (see also Figure 1), this use is increasingly gaining in importance.

The purpose of this publication is to identify and analyse the use of robotics in the food industry and to examine the opportunities and risks of using robots.

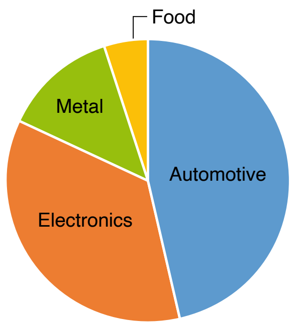

Figure 1: Industrial sectors and robot implementation [according to Grobbelaar et al. 2021]

2 Use of robots along the supply chain in the food industry

An increasing number of companies are coming to recognise the value of automation, particularly of robotics, which plays a crucial role in improving processes. A minority is still dragging their heels when it comes to the introduction of robots. Such companies argue that it will lead to job shedding and that employees will lose their valuable skills.

In the DLG Trend Monitor 2020 'Robots in the Food and Beverage Industry', around half of the companies that were surveyed (52%) stated that they use robots; 48% do not use any robots. A clear trend towards the use of robots is recognisable above all in the dairy industry, but also in the beverages, meat, sausage, poultry and baked goods industries. The number of robots used in a company differs widely and varies between one and more than 100 robots, as can be seen in Figure 2.

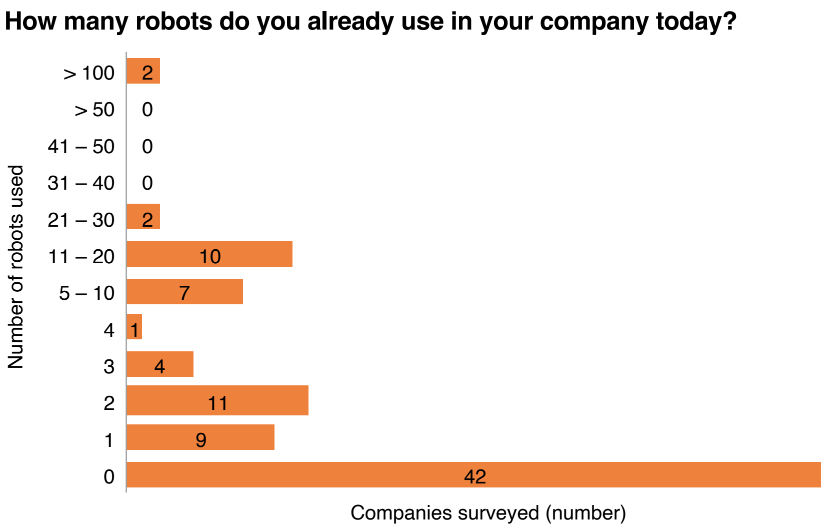

Figure 2: Number of robots used in companies [DLG Trend Monitor 2020]

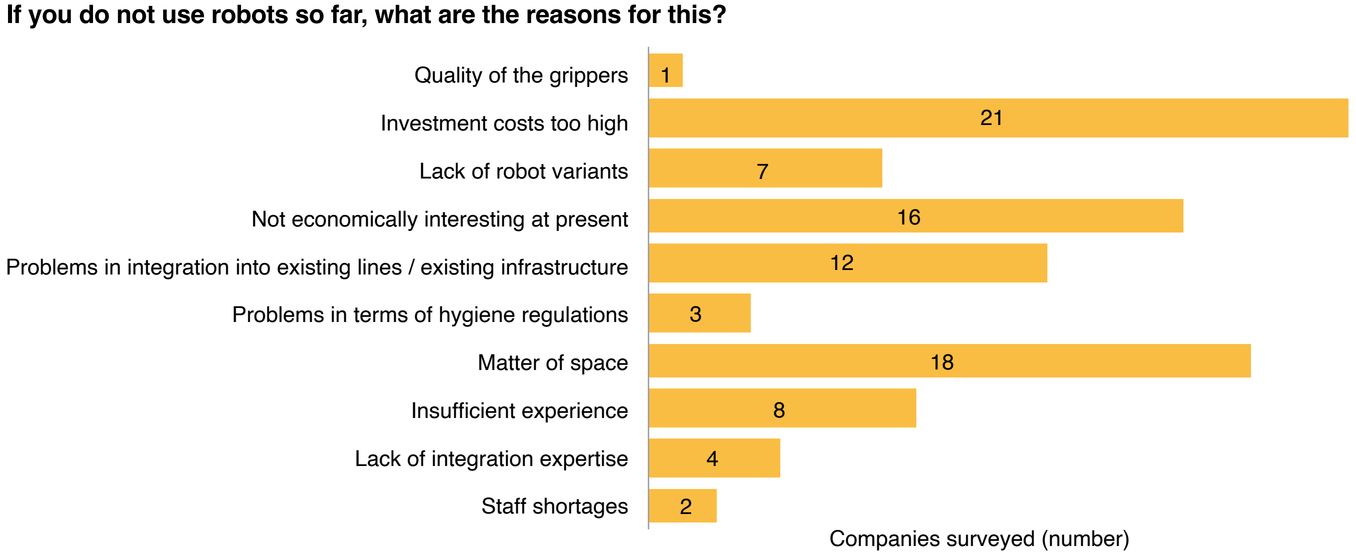

Figure 3: Reasons for not using robots [DLG Trend Monitor 2020]

Above all, the main reasons cited for not using robots are the high investment costs, a lack of space or the fact that robots are not currently economically interesting (see also Fig. 3).

However, 78% of the companies that are already using robots stated that they intended to increase the number of robots in the future. This therefore shows a clear trend towards the use of further robots in companies with experience in their use.

Robot systems can be used in almost all of the production steps along the value chain. The supply chain within the food industry can be broken down into the five areas shown in Figure 4.

The systematisation of existing robot technologies in the food industry was undertaken in the context of a Bachelor's degree thesis at the Hanover University of Applied Sciences and Arts entitled 'Classification and comparison of current and prospective application variants for robotics along the entire food production supply chain'.

This work analysed 80 examples of the use of robots in the areas of raw material delivery, food production, packaging and retail. This revealed that the most widely used kinematics is that of the jointed-arm robot and that robots are particularly used for 'pick-and-place' tasks. Figure 5 shows the areas in which robot applications are used according to the processing process.

The majority of the 59 'pick-and-place' examples that were analysed were used in the area of packaging. Particular attention was paid to innovative robots that are able to undertake more complex 'pick-and-place' tasks such as handling sensitive goods.

Robots are also increasingly being used in technical processing tasks such as 'separating, joining and shaping'. The analysis of the 80 robot applications according to the area of the supply chain is shown in Figure 6.

Figure 4: The food industry supply chain
[based on Weiß 2016]

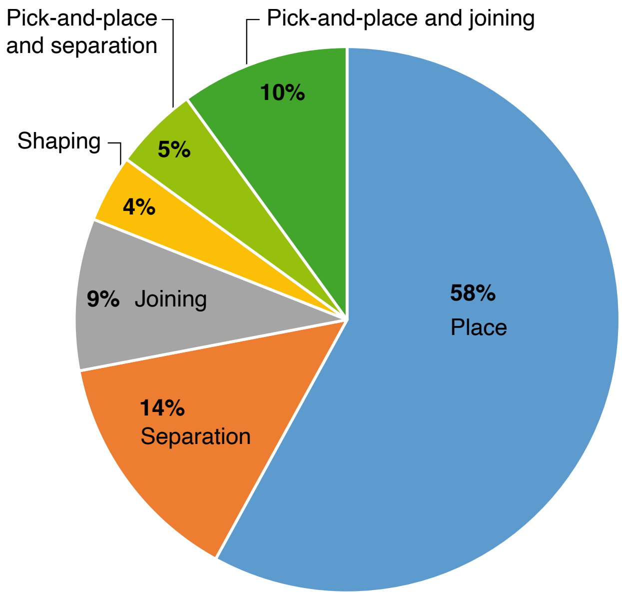

Figure 5: Analysis of 80 robot applications according to processing process [according to Naciri 2019]

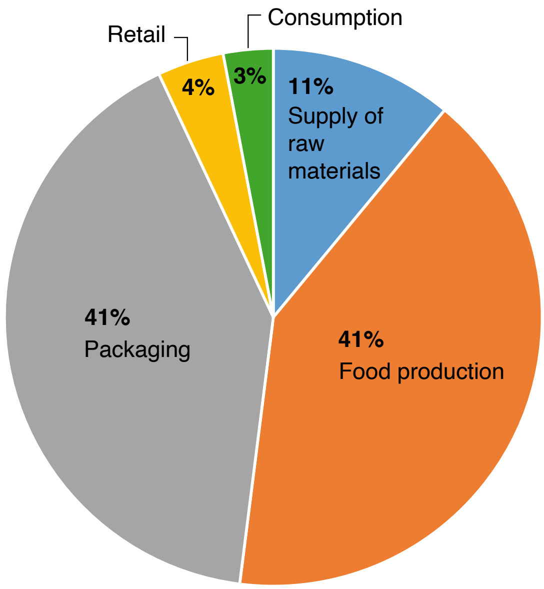

Figure 6: Analysis of 80 robot applications according to supply chain sector [according to Naciri 2019]

3 Type of robots used in the food industry

Definition of robots

An industrial robot is essentially a universal, programmable machine for handling, assembling and processing work-pieces. The machine consists of a manipulator (robot arm), a control system and an effector (tool, gripper, etc.) at the end of the arm. [Maier 2019]

In Standard 2860, the Association of German Engineers (VDI) defines industrial robots as follows: ‘Industrial robots are universally applicable automatic motion machines with several axes, whose movements are freely programmable (i.e. without mechanical intervention) in terms of movement sequence and paths or angles, and are guided by sensors if necessary. They can be equipped with grippers, tools or other production equipment and can undertake handling and/or manufacturing tasks.’

As has already been mentioned, articulated-arm robots (jointed-arm robots) and gantry robots are primarily used in the food industry. Amongst other reasons, this is attributable to the range of applications of articulated-arm and gantry robots. In the field of logistics, robots are particularly used in the area of ‘palletisation’, but also in the areas of ‘depalletisation’ and ‘picking’. In the field of processing, robots are primarily used for ‘positioning’ and ‘sorting’. ‘Repackaging’ is the main area of use in the field of packaging. Therefore, eliminating physically strenuous work such as palletisation still plays a major role in the use of robots. This is also shown by the main reasons stated for the use of robots – ‘labour savings (automation)’, ‘improved working conditions in the workplace’ and ‘cost savings’. [DLG Trend Monitor 2020].

The basic types most often used in the food and beverage industry and the special forms based on them are briefly explained in the following.

- **Articulated-arm or jointed-arm robots (so-called ‘universal robots’):** Universal robots that can move in three dimensions and which are most frequently used in industry. Their kinematics consist of several arm links that are connected to one another by means of joints in order to enable them to guide grippers or tools. They are used universally thanks to their particular manoeuvrability. Their range and carrying capacity are generally high, but limit the speed at which they are able to move; higher speeds reduce their permissible carrying capacities.

- **Gantry robots (area gantry robots, especially for machine loading, palletisation):** Gantry robots, also referred to as linear arm robots, are elevated robot systems that span a cubic gripping area by means of three linear main axes. The crane-like system enables precise movement in a cuboid space. The actual robot kinematics or the moved axes are located above the elevation. They are particularly suitable for transportation tasks, as they also enable very heavy loads to be moved.

- **SCARA robots (Selective Compliance Assembly Robot Arm) (horizontal joined-, articulated-arm or swivel-arm robots):** These consist primarily of jointed arms that can be rotated or swivelled horizontally, as a result of which they bear similarity to a simplified human arm. Each arm link is connected only to one other arm link. Above all, they are suitable for pick-and-place handling. SCARA robots are characterised by their comparatively high rotational speed and precision.

- **Delta robots (parallel robots):** Special type of what are called parallel kinematic machines. They are equipped with three to four articulated axes with stationary drives (spider-like). Such robots can achieve very high speeds and dynamics. However, their carrying capacity is comparatively low due to their design. Delta robots undertake tasks such as pick-and-place applications or handling, assembly and packaging tasks on conveyor belts.

- **Dual-arm robot systems:** This special form of articulated- or jointed-arm robots consists of a torso and two robot arms (articulated arms). This system therefore works in a manner that bears similarity to that of humans. This type of robot is only rarely used at present, however.

- **Combined robot systems:** Various types of robots can be combined with one another. E.g. jointed-arm robots on transport rails (also used in agriculture).

- **Autonomous Mobile Robots (AMR):** These systems enable movement on land, on water or in the air. They are not equipped with solid-state mechanical track guidance, but with sensors for detecting the environment, a plan of the network or predefined logistics in order to be able to perform their specified task. They are used above all for transporting goods, but also for cleaning, inspection or exploration.

- **Collaborating robots (shortened to: cobots) – 'the human colleague':** The tasks of robot systems are becoming increasingly extensive and complex. Direct human-robot collaboration is one possible solution for enabling this increased complexity to be accomplished. The cobot is a mobile or stationary robot with which employees work hand-in-hand without a separating protective fence. Cobots have to be regarded as 'team mates' within a working environment. They are designed such that they can work in close proximity to and together with humans, thereby facilitating the humans' tasks. More time is thereby freed up for humans to perform higher-value tasks, enabling them to undertake more supervisory functions such as quality control while the robots provide support in repetitive, safety-critical, physically strenuous tasks that can prove harmful to humans in the long term. [Naciri 2019, Hesse 2010]

The more extensively humans and collaborative robots begin to work together on more complex tasks, the greater the necessity of effective communication between humans and robots. Collaborative robots are being designed to recognise certain of their human team mates' voice commands and hand gestures. Interactivity will play an important role in robotics in the future. [Grobbelaar et al. 2021]

4 Motivation for the use of robots

The use of robots offers multiple advantages. Some of these advantages will be dealt with in greater detail in the following.

Protection of humans from monotonous and hazardous work

Protective measures with regard to safety and health protection are defined for employees in companies. Various factors can nevertheless pose a risk to humans. Table 1 shows some examples of such hazards. Thanks to the use of robots, these hazards to humans can be reduced or even avoided.

Table 1: Possible hazards to humans [according to Naciri 2019]

Hazards		Examples
Physical forms of stress	• Heavy work: lifting and moving loads • Monotonous, repetitive activities • Mechanical stresses caused by static forced physical postures	• Palletisation • Working on a conveyor belt
Chemical forms of stress	• Liquids and vapours • Chemical burns and intoxication due to harmful substances	• Working with lyes • Working with acids
Biological forms of stress	• Bacteria • Moulds • Parasites • Viruses and prions ➔ Infections and toxic reactions	• Working in a laboratory • Animal breeding in agriculture
Other forms of stress	• High temperatures • Low temperatures • Noise (> 80 dB) • Vibration • Sharp objects • Radiation	• Burning, scalding • Freezing • Damage to hearing • Cuts and scratches caused by knives • X-ray radiation, use of lasers
Mental forms of stress	• Particularly with combinations of hazards	• Monotonous work involving noise (working on a conveyor belt) • Working with hot lye • Cleaning using chemical substances

Not too long ago, nobody believed it was possible that humans would work alongside a robot. Since the technology has been transformed so that robots can work without protective fences, humans are now able to undertake value-added tasks and robots can perform repetitive tasks. They contribute to the general well-being of humans in an ergonomically difficult working environment by taking over tasks such as heavy lifting and the repetitive cutting of fruit and vegetables, for instance. They can help to significantly reduce musculoskeletal disorders, which are a common occurrence in the food industry.

Elimination of manual processes

Manual processes are often expensive due solely to labour costs and can also be hazardous. In particular, monotonous, manual tasks that are repeated on a daily basis are very unattractive to employees. Humans feel that they have more to offer, which is leading to a labour shortage and supporting the increasing use of robots.

Increased production and quality

The systems' precision, speed and efficiency are also positive effects of the use of robots, as they can act to increase production and quality. Multiple factors that can jeopardise the product or the product quality can be found along the entire length of the supply chain in the food industry. Human errors and inaccuracies can endanger the product even during raw material procurement. For instance, microbial contamination can occur if the HACCP concept is not adhered to. Hair, flakes of skin, dirt, and blood, but also viruses and bacteria, can affect product quality and safety.

Inattentiveness on the part of employees can also lead to reductions in quality. Possible defects or pollutants may not be detected due to improper inspection and sorting, for instance, cleaning may not have been carried out sufficiently thoroughly or the product quality may be reduced due to failure to adhere to processing times, e.g. by baking or frying for too long. Automation can prove advantageous here, and product stability can be increased through the use of robots.

Increased productivity

The labour shortage can be solved by using robots. Robots are able to perform monotonous work for hours on end, do not tire and do not need holidays.

Image processing technologies are able to detect and remove foreign objects and defects. This means that food can also be sorted by colour and shape. Laser lighting enables the chlorophyll content to be determined, indicating whether or not the product is fresh. Automated sorting, washing and peeling can improve the quality of products. Robot technology not only improves the process sequence in the sorting area, but also significantly lowers costs without the need for human intervention. [Grobbelaar et al. 2021]

Cost reduction

Employee injuries cost food industry companies millions of euros each year. The most common injuries in the food industry are burns, repetitive strain injuries, cuts and bruises. The costs of these injuries can be subdivided into two groups: direct and indirect costs. The direct costs include medical support, compensation for employees and legal services. Indirect costs can include production downtimes, loss, loss of income, replacement costs and training costs.

Companies can reduce injury compensation costs by providing their employees with safety training and improving safety procedures. The use of robots in food production can reduce the causes of injury-related claims.

Automation can reduce operating and maintenance costs in the food industry. When new standards are introduced, manufacturers can update their existing hardware and software in order to comply with them – at least over a plannable period of time. Preventative maintenance can be supported by automation, which reduces long-term costs. [Grobbelaar et al. 2021]

Elimination of ineffective mechanical processes/adoption of new processes

Slow mechanical processes that are susceptible to malfunctions and can jeopardise quality can be replaced with specific robot technologies.

New, thus far non-existent processes that are highly flexible and modular could also be implemented through the use of robots.

Coping with pandemics and other incidents

The use of automated systems in various forms can ensure the continuous production and delivery of food on a daily basis, even during a period of forced closure (lockdown). Automated systems can be controlled and monitored remotely without having to enter the production area. The factory can therefore operate remotely.

This benefits production during the current COVID-19 pandemic and similar future situations, as automated systems help manufacturers to avoid the risks of personnel losses or food contamination.

5 Challenges to the use of robots in the food industry

With a few exceptions, foodstuffs are not rigid solid bodies and are often fragile and/or easily crushable (plastic or elastic) due to their natural raw materials. Foodstuffs are also susceptible to bacterial contamination and their characteristics are extensively influenced by environmental conditions such as temperature, humidity and pressure. These characteristics of foodstuffs pose numerous challenges in the development and use of robot systems. The most important of these will be dealt with briefly in the following:

Development of various robot end effectors

The development of peripheral components such as sensors that improve the robot's ability 'to feel, to touch, to grip and to see' is indispensable.

Various robot end effectors (often referred to as grippers) have to be developed in order to cope with the wide diversity and the different characteristics of foodstuffs. Robot grippers have be able to handle the texture, the uneven surfaces and the non-uniform shapes of food and to meet hygiene requirements. Robot end effectors also have to adapt to the food, e.g. to wet and sticky surfaces. Due to reasons of contamination, the robot end effectors must contain as few mechanical components as possible so that these do not enter the food product. They also have to be operated at high speed in order to achieve an appropriate cycle time. The effectors should additionally be inexpensive and meet the principles of hygienic design. Figure 7 shows gripping options.

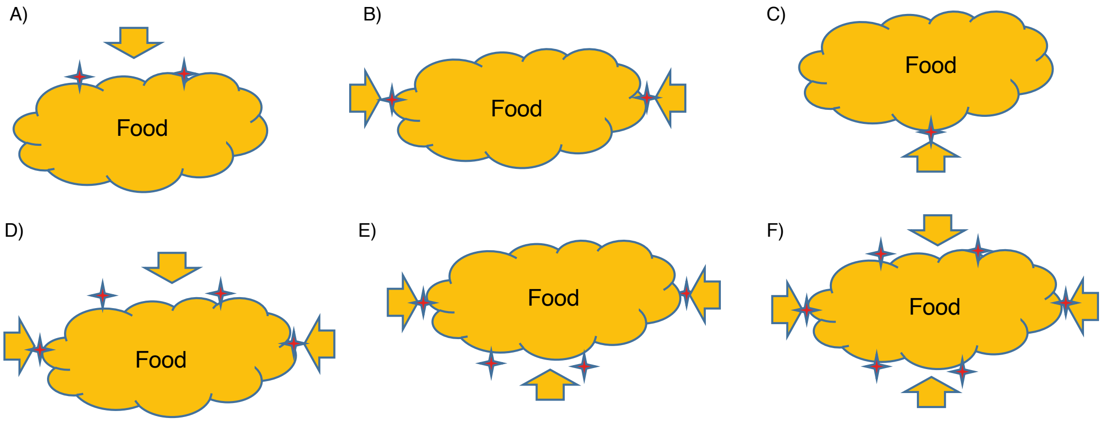

Figure 7: Different types of robot end effectors according to their handling position:
(A) top, (B) side, (C) bottom, (D) top and side areas, (E) side and bottom areas and (F) top, side and bottom areas.
Red stars indicate the contact positions.

[Own diagram according to Wang et al. 2022]

If the gripping principle is considered, only end effectors that grip at the top and the side surfaces have been analysed and commercialised properly. Conversely, end effectors that grip from the lower side and from all surfaces have hardly been analysed. However, such end effectors are necessary for handling different types of food, particularly slippery, heavy and flat foodstuffs.

Recognition of foodstuffs

The difficulties involved in recognising foodstuffs vary significantly depending on application scenarios. 2D or 3D technologies have to be used, for instance, which still poses a major challenge in some cases.

Fundamental information

An effective handling strategy can prove very helpful to achieve successful food handling. For instance, the gripping force must be sufficiently low to avoid damaging the food. Conversely, it must also be sufficiently high to ensure that the food is gripped securely. The gripping speed also plays an important role, particularly when the viscosity of the food is taken into consideration.

However, fundamental information for modelling the correct 'technical' characteristics of foodstuffs, such as the size, shape, weight, softness, surface characteristics, coefficient of friction, viscoelasticity, rheology, fragility and pressure sensitivity, for instance, is often missing.

Research in this field is rare, particularly from the perspective of using a robot. There are specific machines or devices for measuring these characteristics that are used for research purposes. Unfortunately, hardly any such data is available for robot handling, but it is important for developing end effectors and conducting research into gripping strategies.

In order to maximise the cost efficiency of a robot, it is important to analyse how many categories of foodstuffs an end effector can process.

In view of the great diversity, it is not cost-effective to conduct experimental tests for each individual food product. Foodstuffs therefore have to be categorised under the aspect of robot handling in order to facilitate development.

The development of specific databases and digital twins will also help in the future. Only databases that refer to sub-areas such as the nutrient profile, the food composition and the food ingredients are available at present, however. There are not yet any databases that can be applied directly to handling by robots. [Wang et al. 2022]

6 Opportunities & limitations

Hygiene requirements for robot systems in food production

One of the biggest challenges in automation is compliance with HACCP standards and therefore all aspects of hygiene during every production step. Consequently, the robots should be manufactured so that they are easy to clean and no loose wires are connected to the robots. The material used to manufacture the robot must also be food-safe.

Humans play a crucial role in the transfer of microbes to food. The objective is to prevent or minimise the transfer of contamination, bacteria and viruses to food by means of personal hygiene measures. Due to the direct collaboration between humans and robots and the resulting 'open production', cobots number amongst the particularly critical processes with high hygiene requirements for employees. It must also be ensured that people such as external staff who carry out repairs or maintenance on the cobots, for instance, wear accordingly clean work clothing.

The sources of risk that play a role in food are summarised in Table 2 in the following (according to Ullmer 2015).

Table 2: Food hazard categories [according to Ullmer 2015, Makowski 2021]

Category	Description	Examples
Biological hazards	Undesired microorganisms, pathogens or toxins produced by microorganisms that can enter the product or develop in the product.	Moulds, yeasts, bacteria, viruses, pests, etc.
Chemical hazards	Undesired chemical substances that make the product unsafe for the consumer. These hazards may already be present in raw materials or may enter the product or develop in it during production, storage and transport and contaminate it.	Pesticides, heavy metals, acrylamide, environmental pollutants, dioxins, lubricants, cleaning agents, additives from packaging materials, printing inks
Physical hazards	Foreign constituents that may be present in raw materials or that may enter the product during production, storage and transport.	Foreign bodies, particularly splinters or particles of glass, plastic, wood, metal, packaging material

The risk of food becoming contaminated is always present, but must be limited to a permissible minimum. Food hygiene is imperative along the entire value chain. However, focus is placed on production hygiene, and particularly on food processing systems, in the following.

Hygienic design (abbreviated to HD)

Hygienic design describes the design of construction components, devices and production systems to ensure ease of cleaning in food production. Robot systems also have to comply with the technical and legal requirements in order to be used with food.

The following **technological aspects** have to be observed and implemented for an assessment and hygiene-friendly design:

- **Construction materials** influence cleaning and determine whether manufacturing is feasible. From the point of view of hygienic design, food processing machinery is subject to additional requirements in accordance with the EU Machinery Directive. Materials of parts that come or can come into contact with the products must comply with the relevant directives. This includes the fact that these materials must be physiologically safe, no impermissible material contents may migrate from them into the food to be produced, the surfaces must be flawlessly manufacturable with the required surface quality and the surface quality should not deteriorate during the service life of the materials wherever possible.
- The **lubricants** used in mechanical joints must meet all food legislation requirements at national and international level, must not pose a health hazard and may not influence the sensor systems in any way.
- The **design of the surfaces** must observe the fundamental criteria for the design of systems, apparatus, components and devices in accordance with hygiene aspects. Ease of cleaning can be achieved by adhering to or complying with fundamental construction and design principles, for instance. This includes, for example, the production of suitable, adequately smooth microstructures on surfaces that come into contact with the product in coordination with the characteristic properties of the materials used, the avoidance of pores, cracks and gaps of any kind and the streamlined design of product areas.
- **Welding** is the most frequently used method for joining stainless steel in apparatus construction within the food industry. A welded joint offers optimum technical safety for all weldable materials; when designed in accordance with HD standards, it also offers microbiological safety.
- **Separable connections** (especially threaded connections) should only be used if it is absolutely necessary to dismantle or release components. A variety of problem areas occur at such connections from a hygiene perspective. These are related to the component connections, the shapes of screw heads and nuts and the tolerances in the threads and holes.

Seals that come into contact with the product are often the most sensitive elements in terms of designing for ease of cleaning. They are often made of elastomers and rubbers, which can expand or contract as the temperature fluctuates. This can lead to leaks and contamination.

In practice, product batch recontamination that is often not immediately visible is caused by sealing points that are not hygiene-friendly. Cleaning and sterilisation at these problem points are often unreliable. In practice, a great deal of contamination is attributable to unsuccessful cleaning of gaps, dead spaces in seals and cracks in seals. However, recalls of contaminated products can lead to high costs.

The constructive, HD-friendly design of the geometry of surfaces in the product area is crucially important for cleaning systems, components and apparatus. Surfaces must be smooth, continuous or sealed. Angles and corners should be rounded, steps, gaps and dead spaces should be avoided and emptying should be ensured.

In addition to the technological aspects, there are also product-specific risk factors. A robot that does not originally pose a risk may subsequently pose a hygiene risk if food is produced in the system. All interactions between the robot system and the food must be taken into consideration in this case. For instance, foodstuffs that are not pH-neutral attack the aforementioned seals, enclosures and general surfaces. The more perishable the product is or the more the multiplication of pathogenic microbes is fostered, the greater the hygienic sensitivity.

As an additional basic parameter, the cleaning of areas that come into contact with the product also plays a role in the risk assessment, as this can enable the product risk to be reduced and possibly even eliminated. [Hauser 2008, Makowski 2021.] On the other hand, the effect of the cleaning media on the robot system must also be taken into consideration.

Besides the hygiene aspects to be implemented, it is also crucial to reliably prevent the ingress of foreign objects (e.g. metals, splinters of glass or wood, flies, parts of seals, etc.) into food by identifying and avoiding potential ingress paths, amongst other factors.

Packaging

The fact that the primary packaging comes into direct contact with the food must be taken into consideration from a microbiological perspective when classifying primary, secondary and final packaging. As a result of this, the primary packaging has to be regarded as particularly critical. Secondary packaging (multipacks) and final packaging are now subject to hardly any microbiological requirements. This is clearly shown by the following example:

Slices of cheese are picked up with the aid of a delta robot using the pick-and-place process and are placed precisely into the intended packaging, e.g. blister packaging (primary packaging).

Examples of secondary packaging (multipacks) include the insertion (top-loading) of cheese blister packaging into shipping boxes using SCARA robots or the filling of reusable boxes with articulated-arm robots. Palletisation of the shipping boxes with the aid of an articulated-arm robot is an example of final packaging.

Delta robots offer advantages thanks to their parallel kinematics. Their vertically slanting arms prevent product residues from accumulating or cleaning agents from remaining behind. The disadvantage of gantry robots and SCARA robots is that product residues or cleaning water are unable to drain away easily due to their horizontal surfaces. It is also considerably more difficult to seal gantry robots over longer distances. On articulated-arm robots, there are numerous moving parts to note from a hygiene perspective.

Maintenance of the robots

Robot systems must be able to withstand the conditions in food production, such as a wet, cool environment and high humidity as well as cleaning agents and disinfectants with different pH values, for instance. The detachment of materials such as paint coatings, glass splinters or corrosion must not pose a risk to the foodstuffs. Proper maintenance is also important for work safety.

Cleaning and disinfection

The objective of cleaning and disinfection measures in food production companies is to interrupt contamination chains. Production residues such as proteins in meat, fish and milk processing or animal and vegetable fats, but also carbohydrates, tannins, inorganic contaminants (e.g. calcium phosphate, water hardness, etc.), stabilisers and emulsifiers have to be removed. As has already been described, the robots that are used should be resistant to the cleaning agents and disinfectants. Cleaning and disinfection necessitate trained personnel who are familiar with the robot's critical areas (e.g. corners, seals, etc.).

However, the use of robots in cleaning and disinfection also reduces the risk of contamination by personnel at the same time, as the personnel do not come into direct contact with the foodstuffs and the work is instead carried out by robots. Cleaning requires a high level of care and therefore a great deal of time, including the associated personnel costs. The use of robots that work through their strictly programmed process can prevent contamination and also reduce costs. Mobile systems that remove microbial contamination from surfaces with the aid of UV radiation are used in medicine, for example. The costs and benefits have to be weighed up in this case. [Brünger 2021]

7 Optimisation potentials thanks to kinematic reversal

Kinematic reversal describes the change in the movement patterns of two objects in relation to one other. In robotics, it describes the reversal of movements from the tool moving towards the goods to the goods moving towards the tool. This restructuring is aimed, for instance, at increasing efficiency, optimising the use of resources (space, energy or time) or improving safety and hygiene conditions.

Robotics costs are declining. The robot market, which is also growing exponentially, is offering an increasing number of solutions for various application areas and is therefore also catering to an increasing number of special solutions. Kinematic reversal could prove helpful in this case with different solutions. It can generally be stated that the use of kinematic reversal is sensible when tools or goods are moved despite the lower weight of the counterpart. The merger of movements of the same kind can also prove valuable. Instead of these similar kinds of movements being carried out in succession, they can be processed in parallel, thereby saving resources.

Due to the current trend towards rising energy costs, however, cost/benefit statements must always be examined and analysed individually. [Brünger 2021]

8 The future role of robots in the food chain – practical examples

A few decades ago, nobody believed it was possible that humans and robots would work together as a team. Previously, robots only performed one single task and were literally ‘fenced off’ in order to prevent them from endangering humans. The future of robot and human collaboration (HRI or Human-Robot Interaction) in a working environment appears promising and is continuing to progress.

Cobots do not require the same amount of space as a standard industrial robot. They are designed so that they can work alongside humans in tight spaces, enhance human capabilities and optimise processes. Thanks to their integrated sensors, they are very safe and significantly more reliable than the robots of the past. Cobots are entirely mobile and can move effortlessly from one place to another.

The industry’s interest in collaborative robots is increasing day by day. Further developments are additionally playing a crucial role. Some examples of these are briefly summarised in Table 3.

Table 3: Robots and the latest developments in the food chain in 2020 [examples according to Grobbelaar et al. 2021]

Description	Characteristics	Use above all in the following industries
Drones	Drones provide farmers with an overview of their agricultural land and help them to make sound decisions that maximise crop production by using advanced sensors and imaging technologies as well as hyperspectral and thermal imaging technologies.	Agriculture
Cobots	Cobots can disinfect cows’ udders without posing a risk to humans or animals; they can successfully milk cows and collect eggs from the hen house.	Dairy and poultry farms, food production, packaging and palletisation
Image-controlled robots	Image-controlled robots are used for sorting by colour, shape or size, and the improved gripper technology can help with sensitive products, e.g. in pizza production and for biscuits.	Bakeries, snack industry
Packaging robots	Packaging robots can open, fill, pack and seal packaging and label it correctly for shipping to the end consumer.	Mass production

Agriculture

The world needs more food because the global population is growing. The younger generation's interest in working on farms is decreasing, leading to a shortage of workers on farms around the globe. Robotics can solve this labour shortage, for instance, by milking and feeding dairy cattle and collecting eggs on farms. Robots can make an important contribution to curbing the food crisis.

The right timing and correct handling are critical when it comes to harvesting fruit. Fruit and vegetables are difficult to handle with a robot due to their different sizes and shapes. The work also needs to be carried out very carefully to avoid damaging them. Research into flexible grippers for raspberries and strawberries, for instance, is making progress.

Food production/processing

Customers' requirements are constantly changing due to increasing information. Cobots can improve flexibility in production and reduce the amount of physical labour.

Robots are also being used in slaughterhouses. Due to the nature of the work in this industry, robots are used separately from humans in order to reduce the risk to employees. Carcasses are very different and vary in size and shape and even in terms of the number of ribs. Some of the activities in the slaughtering process are easier to automate than others. A high-speed circular saw is required for cutting ribs, which is very dangerous and repetitive work. The risk of injuries increases when staff become tired or are distracted by personal problems. Robots can remedy this situation.

One impressive application is robot-aided cake decoration. In this process, a robot arm is used similarly to a 3D printer in order to apply icing onto a cake. However, it cannot be used as a substitute for human creativity.

Food packaging

Increasingly few workers are willing to undertake the job of packaging and palletising food. Ever more food production companies are using robots for packaging and palletisation. They reduce monotonous, repetitive human tasks and the general strain on the health of personnel. It is estimated that over 90 percent of food manufacturers are already using robots to support them in this task. Robots can be used for primary, secondary and also tertiary packaging.

Delivery service

Delivery robots are light and are able to deliver orders weighing up to 10 kg autonomously. They are equipped with 360-degree cameras, for instance, and are intended to be able to navigate and move both along streets and across uneven terrain in equal measure.

Tests using drones to deliver medical goods in rural areas have already proved promising. Drones that deliver food and critical medicines to various areas are conceivable. However, further research and testing are required before this becomes part of our everyday lives.

9 Summary and outlook

The number of production robots used in other industrial sectors, particularly in the automotive industry, is high, but the use of robots in the food industry is also becoming increasingly important. Research work is being conducted in the development of robots, particularly in the agricultural sector (delivery of raw materials), but also in the consumer sector (catering), in order to achieve successful automation. Development in this area is primarily related to the shortage of labour. Demand remains high despite the development of innovative solutions.

Collaboration between humans and robots is increasingly attracting industrial interest. This is leading to the continuous development of cobots.

In the food industry, robot systems are particularly used in the field of packaging in order to relieve the strain on humans involved in monotonous and physically demanding work. Any risk factors that could affect the food from a hygiene perspective must be taken into account during production.

However, robots can never completely replace humans. So far, robots are unable to develop any creativity or passion or a love of food. Robots are preferably used for work that is hazardous to health and/or monotonous and repetitive.

Numerous requirements have to be observed, particularly in the area of hygiene, when robots are used in the food industry. Besides the risks, however, the use of robots also offers numerous opportunities. The growing need for production improvements, the constant necessity to complete tasks faster, the numerous challenges posed by labour shortages and customers' ever-increasing product consistency requirements may all be factors that speak in favour of the use of robots.

Like any strategic decision, investing in robotics must be looked at holistically by every company.

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