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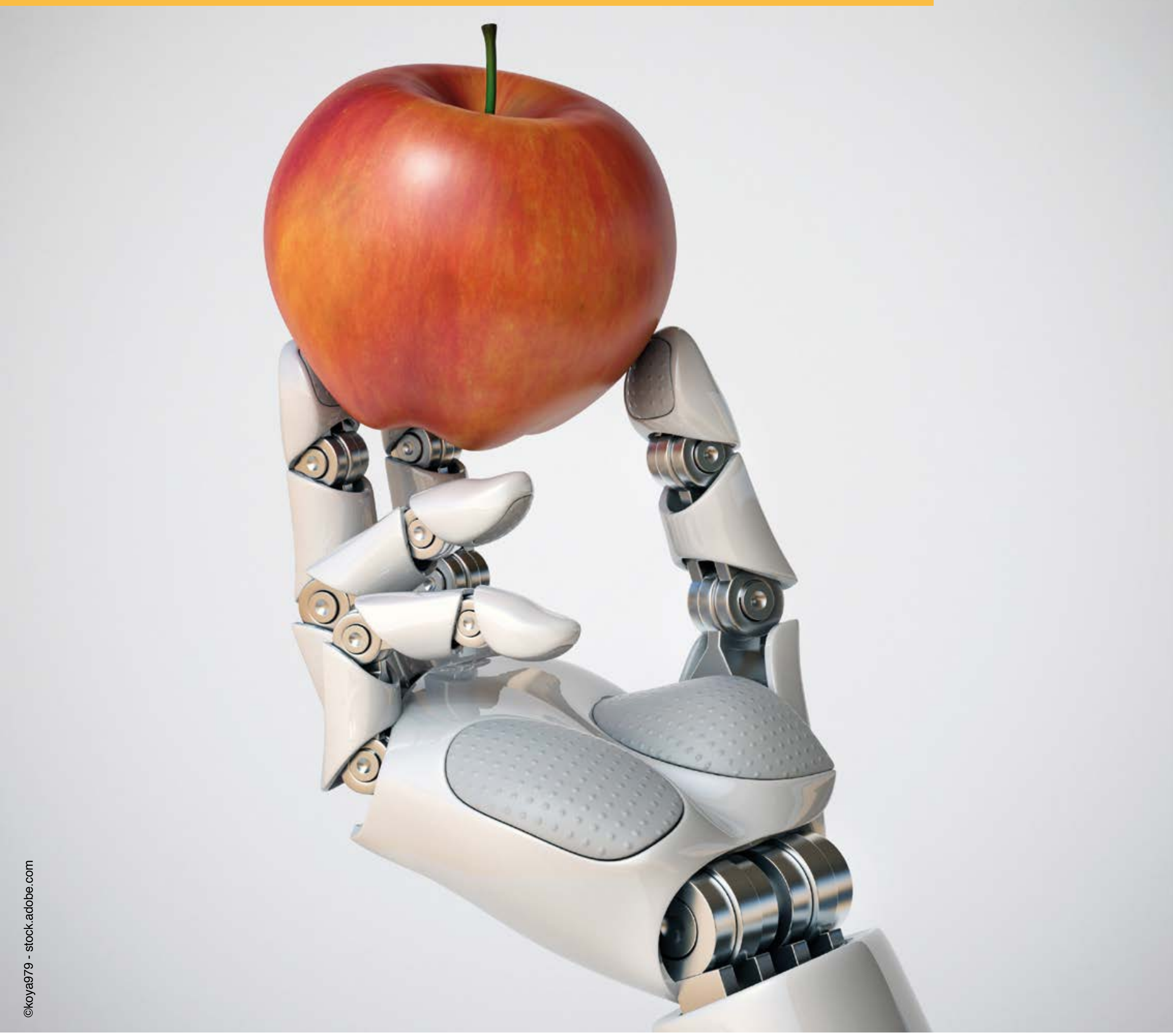
Robot Grippers for the Food Industry

Product-Specific Solutions



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In the course of advancing automation, it is no longer possible to imagine the modern food industry without robots. Significant progress in terms of the hygienic design of robots, automatic image acquisition and evaluation, as well as in the field of gripper technology mean that robots can now also be used in direct contact with food and can be entrusted with increasingly difficult tasks. The aim of this publication is to provide an overview of the gripper systems currently available on the market for applications in which the grippers come into direct contact with unpacked food.

Gripping is a basic movement in robotics for grasping and holding objects, e.g. workpieces or food. Technically speaking, grippers are subsystems of handling devices that establish a temporary contact, i.e. a temporary connection, between the robot and the gripped object. They secure the position and orientation when picking up and during placing of objects with respect to the handling device. The term "gripper" is also used when something is not gripped in the actual sense, but is instead held using forces acting on the surface, as is the case with vacuum cups, for example.

A safe connection is crucial for proper functioning, which depends on the type of active pairing as well as the number and size of the contact levels. The effect pairing, for its part, can be achieved via force, form or substance pairing. In the case of force pairing, a pure friction pairing, the hold is created by exerting a pressure on the surface of the workpiece or food. Shape pairing is used to describe holding by enclosing the object with more or less the same shape. An advantage with regard to sensitive foodstuffs is that the transmitted clamping forces are very low. Finally, in the case of a substance pairing, contact with the object to be handled is achieved by exploiting adhesion.

Depending on the operating principle, a distinction can be made between mechanical, pneumatic, pneumostatic/pneumodynamic, electrical and adhesive grippers, whereby almost all operating principles can also be found in connection with food handling.

Grippers for the food industry

As the last element of a kinematic chain, grippers, also called effectors or end effectors, represent one of the most important aspects in the solution of automation processes in the food industry with the help of handling devices or manipulators, as they are intended to replace the human hand here. They are therefore the interface between the robot and the food. In addition to the general requirements for grippers summarised in Table 1, those used in direct contact with food must meet two basic food-specific requirements: On the one hand, gripper systems must also meet the high hygienic requirements of the food industry, and therefore also the specifications of hygienic design without compromise, as well as being comprehensively cleanable and disinfectable (see Table 2).

Technological requirements
Gripping time and distance
Gripping force curve
Number of objects to be gripped per gripping action
Influence of the gripping objects
External shape (tolerances)
Mass
Surface properties
Strength
Influence of the robot (handling device)
Positioning accuracy
Acceleration/deceleration of the axes
Connections
Environmental parameters
Feeding devices
Environmental conditions (temperature, humidity)

Tab. 1: General requirements for grippers [Hesse et al., 2004]

On the other hand, solutions are required which are matched to varying physical and mechanical properties of the respective food in more or less far-reaching areas. After all, the grippers should do their job without destroying the product or leaving visible marks on its surface.

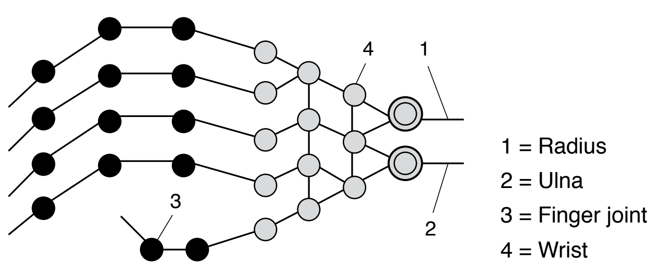

Figure 1: Mechanical joint structure of the hand [Hesse, 2011].

Hygienic design
Hygienic design is the cleaning-friendly design of parts, components and production facilities.
The constructive design takes into account the requirements for cleanability so that all areas are avoided where dirt can accumulate and pose a risk to the food.
Effective and safe cleaning of production facilities requires components that are easy to clean.

Tab. 2: Hygienic Design – an important building block for ensuring food quality [Franke, 2010]

Principle	Advantages	Disadvantages
Mechanical grippers (incl. needle gripper)	• Hygienic design possible	• Limited reach • Surface influence on the food
Overpressure gripper	• Completely closed • „Soft“ contact pressure	• Limited reach • Limited gripping force
Vacuum suction cup	• Variable in terms of dimensions	• Sucking in of product residues or moisture
Airflow gripper	• No sucking in • Simple shape	• Firm, smooth surfaces required
Electrostatic gripper	• Low mechanical load	• Low adhesive force

Tab. 3: Gripper principles and their suitability for use with food [modified after according to Franke and Hukelmann, 2014]

As a result, it is not surprising that in the development of grippers, people always look to the human hand, which has a degree of freedom of F = 22 due to the joints shown in Figure 1, making it probably the most universal gripper of all. For most industrial applications, this flexibility is far from necessary, and as a result task-specific gripper systems are often developed.

Table 3 provides a basic assessment of the advantages and disadvantages of some gripper principles with regard to their use in direct contact with food.

Mechanical grippers

Mechanical grippers are available in greatly differing designs depending on the respective task. A basic classification distinguishes between single-finger, two-finger or multi-finger grippers, each in rigid, rigid-jointed or elastic design. They can be driven mechanically, pneumatically or electrically, whereby the pneumatic drive is widely used due to its ease of handling.

Since the beginning of this century, the first mechanical grippers have been available that were constructed for direct contact with foodstuffs by consistently applying the rules of hygienic design. This makes them interesting not only for the food industry; they are also suitable for use in the production of medical or pharmaceutical products. Among the first grippers of this type were the gripper modules of the LMG product series from Schunk. With their completely sealed housing made of corrosion-resistant, polished stainless steel, they easily withstood the cleaning and disinfection agents commonly used in the industry and could even be cleaned with the aid of high-pressure cleaners. In terms of design, these were angle grippers with an adjustable opening angle of 20° to 180°. To prevent the loss of a food product in case of a pressure drop, the grippers were equipped with gripping force retention by an integrated spring. A direct connection was used for the hose-free supply of compressed air to the gripper for gripper actuation. While the LMG series is no longer available on the market, similar gripping modules are now offered by numerous manufacturers.

In order to be able to handle a foodstuff optimally, the gripper fingers must be adapted to the properties of the respective foodstuff. In practice, this means that relatively few finger types are offered as standard for mechanical gripper modules. In most cases, they are designed according to need and produced customised.

Whereas in the past this could only be achieved with great effort, industrial 3D printing has been opening up almost unlimited possibilities for gripper and suction cup solutions for around 10 years now, which can also be realised economically. In 2015, Lehmann & Voss launched Luvosint 65-8824, a polypropylene (PP) for laser sintering of robotic grippers, which in turn enables new innovations. Due to its low specific density, the material is about 10 % lighter than PA12, which is of great importance in high-speed robotic applications. The high toughness of the material also enables the construction of space-saving, compressed air-driven actuators. And because Luvosint 65-8824 does not absorb moisture, it does not become brittle through contact with dry compressed air. For food applications, it is extremely important that this also prevents microbial growth.

DHAS adaptive gripper finger

One Bionic product is the adaptive grippers offered by Festo, called FinGripper Fingers, which make use of the so-called Fin Ray Effect® (Fin Ray Effect® is a trademark of EvoLogics GmbH, Berlin). This was copied from the tail fins of bony fish, which bend against a force acting on them.

One possibility for the technical implementation of this effect are the FinGripper Fingers. They consist of two flexible plastic bands that converge triangularly in a point. Rigid cross struts are inserted at regular intervals, which are connected to the ligaments by joints. Due to this flexible but at the same time firm connection of the limbs, the gripping fingers can adapt to the contour of an object when lateral pressure is applied (Fig. 2).

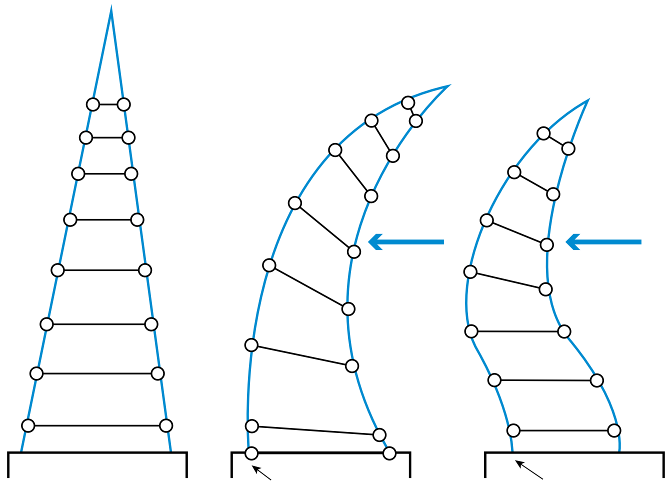

Figure 2: Function of the Fin Ray Effect®

The FinGripper fingers are manufactured in one piece as a complete part including the cross struts and their bearings using 3D printers. These work in the selective laser sintering process, in which layers of polyamide powder 0.1 mm thick are applied one after the other, which then harden to form a solid component. In addition to their function, the advantage of these grippers is their low weight, which enables very energy-efficient gripping and moving of objects.

Adaptive gripping can be used for many different tasks, but it is primarily characterised by the adaptation of the structure to different object contours, so that not only differently shaped and differently sized, but also pressure-sensitive, fragile objects can be moved and positioned without damage. Calculation programs are available for the design and size of the FinGripper to be used, but as a guideline it can be assumed that the diameter of the objects to be handled should roughly correspond to the length of the gripper finger.

Figure 3: DHDG adaptive gripper from Festo

Elastomer grippers

This group of grippers also includes the elastomer gripper developed by the Fraunhofer IVV (Research Institute for Process Engineering and Packaging) in Dresden, which is based on the scientific and technical results of a cooperative project (of the IGF project no. AiF-FV 404 ZBG) with the Deutsches Institut für Lebensmitteltechnik e.V. (DIL – German Institute of Food Technologies) and the Deutsches Institut für Kautschuktechnologie e.V. (German Institute for Rubber Technology).

The basic element of elastomer grippers are so-called flex fingers, which consist of a soft, stretchable material. By making one side of the material non-stretchy or less stretchy than the other, an increase in pressure inside the finger causes the finger to bend around that side. When the pressure is released, the flexion goes back again.

The elastomer gripper has been constructed according to the conditions of hygienic design and complies with current hygiene standards. In practical terms, this means a completely enclosed design so that the product area is safely separated from the inside of the gripper. The grippers are designed to be cleanable and can be cleaned and disinfected without dismantling.

The advantages of elastomer gripper technology are summarised by the IVV as follows:

- Minimisation of hygienic risks
- Flexible and gentle gripping and therefore safe and non-destructive handling of sensitive foodstuffs
- High adaptability across a broad range of products
- Great format flexibility
- High productivity

Figure 4: Elastomer gripper

Vacuum grippers

In addition to mechanical grippers, there are a variety of gripper systems that work on the basis of vacuum technology. In order to be able to design these widespread systems functionally and economically, it is necessary to create an optimum of load-bearing capacity, compressed-air consumption, tolerance to product residues such as detached breading particles and tolerance to compressed-air leakage, which can occur due to incomplete covering of the suction surface.

For direct contact with food, gripper constructions made of stainless steel as well as individually designed suction pads made of food-approved silicone polymers are used. These deform in a defined way during suction due to their fluid mechanics. This means that such grippers can also be used to precisely suck on irregularly shaped objects, such as chicken fillets or legs, while partially enclosing them as with a mechanical gripper, resulting in a secure grip with low vacuum. For standard tasks such as handling a predefined arrangement of geometrically uniform objects, modular systems are already available today with which the appropriate gripper tool can be assembled from standard parts and also modified again if required.

Vacuum cups used in pick & place applications all have the same task – in accordance with the meaning of the term: Picking up and moving parts. Depending on the shape, size and material of the objects to be handled, different suction cups are used:

- **Bellows suction** cups are used when there are differences in height to be compensated for
- **Flat suction cups** offer the best stability on flat surfaces
- **Oval and ring vacuum suction cups** are used in confined spaces

The transfer of packaged sausage products into cartons should be mentioned as an example of a case in which suction cups had to be specially adapted to the specified conditions during application. The critical point in this case was the fact that the surface of the packaging is flexible and the film gives way. FIPA experts therefore suggested the use of oval suction cups 1.5 bellows, which are vulcanised onto aluminium plates. Height differences, which are caused, among other things, by the bending slackness of the sausage packs, are compensated for by the bellows. The aluminium

Advantages of vacuum grippers
A free surface on the object is sufficient for gripping • External dimensions of the object can vary greatly
Only the permissible leakage rate must be overcome • No further requirements must be met for gripping and transporting the object • The gripper need not necessarily be exactly positioned • Higher error tolerance with regard to object detection
The objects need not be encircled • No clearance is required between the products • Objects need not be separated. For example, several slices of sausage lying on top of each other can be grabbed at once.

Tab. 4: Advantages of vacuum grippers [Franke and Hukelmann, 2014]

Bellows suction cups for chocolates | Flat suction cups for chocolates | Bellows suction cups for eggs*

© FIPA

* Gentle set-down on the egg and large lifting movement due to very long suction stroke

Figure 5: Examples of vacuum suction cups

plate ensures the flat stability of the suction cups and support ribs arranged in the oval of the suction cup prevent the film from being sucked in. The operation is supported by the fact that the flexible lips of the suction cups, which are made of vinyl, adapt well to the surface texture of the packages.

Vacuum suction cups and food safety

With regard to food safety, it must be remembered that parts of the suction cups can get into the food in the course of the working process. Therefore, measures are taken today to detect such parts, and therefore to be able to sort them out again. One possibility is to dye the suction cups blue, a colour that rarely occurs in food and is therefore quickly seen. More effective, however, is the use of suction cups made of a material that can be detected with the help of metal detectors. An example of this is silicone doped with small amounts of a metal oxide.

HDHF grippers

One of the more recent innovations in the field of vacuum grippers is a development by the Deutsches Institut für Lebensmitteltechnik e. V. (DIL- German Institute of Food Technologies) in Quakenbrück, Germany. The objective was a gripper system that is easily and completely cleanable and as versatile as possible under the conditions in the food industry. In order to be able to guarantee flexibility in handling foodstuffs with widely varying dimensions, the principle of vacuum suction cups (vacuum grippers) was used. In contrast to previously available vacuum grippers, the holding force for the product is applied via a vacuum between the gripper and the food surface. In the design and construction of the so-called HDHF grippers (Hygienic Design, High Flux), the requirements of hygienic design were consistently taken into account without compromising the advantages of the vacuum gripper. The necessary vacuum is generated directly in the gripper so that there are no hoses or pipes that could become dirty inside. Furthermore, the gripper has been designed in such a way that blockages due to extracted product particles are largely excluded. A high air amplification factor was integrated by means of suitable air guidance when generating the vacuum from compressed air. This enables safe transport even with partially air-permeable objects. Using suitable sensor technology, it is also possible to apply defined forces and document the successful transport process or count the number of objects inserted. All parts of the gripper are made of food-grade stainless steel or corresponding plastics. The gripping concept itself is based on the combination of the universally applicable HDHF vacuum generator with a product-specific gripping bell. Matching the suction cup with the respective product poses few problems, as the suction cups can be realised using a 3D printing process. In some cases, commercially available

Attributes	HDHF grippers	HDB* grippers
Requirements for "hygienic design" met?	yes	yes
Area-related holding force	moderate (up to 35 % vacuum)	low (up to 15 % vacuum)
Compressed-air consumption	moderate (120 l/min)	moderate (180 – 250 l/min)
Leakage tolerance	high	very high
Product-specific suction cups available?	yes	no
Special properties	High leakage tolerance	Leakage-independent operation

*Tab. 5: HDHF and HDB grippers in comparison [Franke and Hukelmann, 2014] (*HDB = Hygienic Design, Bernoulli)*

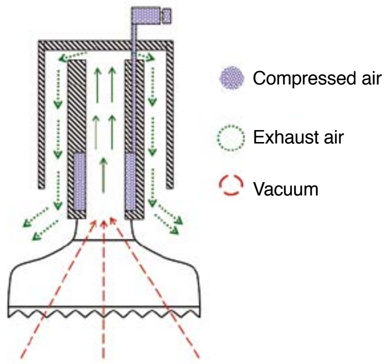

Figure 6: DIL HDHF vacuum gripper

Figure 7: DIL HDHF-mini with silencer

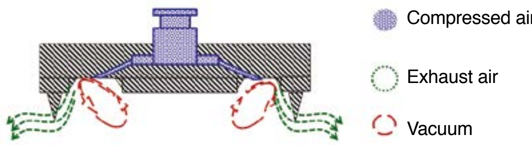

Figure 8: DIL HDB vacuum gripper

Figure 9: DIL HDB vacuum gripper

Fig. 6 - 9: © DIL

rubber suction cups can also be adapted to the HDHF. As previous experience has shown, almost all non-liquid foods can be handled with the help of this gripper.

Electro-adhesive grippers

Researchers at the École polytechnique fédérale de Lausanne (EPFL - Swiss Federal Institute of Technology in Lausanne, Switzerland) are pursuing a new approach. The prototype robot gripper they developed is, for example, gentle and flexible enough to grasp and hold an egg or a single sheet of paper. On the other hand, it is so strong that it can lift 80 times its own weight.

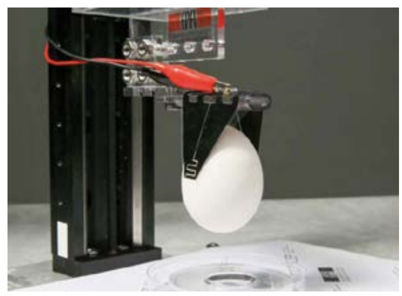

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Figure 10: Electrodes that provide electro-adhesion enable the Lausanne EPFL's Softgripper to hold even fragile objects

The basis of the gripper are two flexible, soft rubber wings with integrated electrodes that can be interpreted as a thumb and an index finger. The gripper owes its firm grip to electro-adhesion. The electrodes are arranged in the wings in such a way as to maximise the electric field generated, resulting in a tenfold increase in the electro-adhesion effect compared to conventional arrangements.

When at rest, the two wings roll outwards. When an electrical voltage is applied, the wings are charged in opposite directions and bend inwards, fixing any object that lies between them, regardless of its shape. And the wings are fast: They only need about 200 milliseconds to react to the voltage. According to the EPFL researchers, this is the first time that electro-adhesion and soft robotics have been combined. With the help of integrated sensors, the gripper can control itself and handle objects with special or varying shapes.

Mechatronic model

Modern gripping systems consist of a basic operating principle, a mechanical design with a kinematic structure and electronic elements. CAD data alone are not enough to completely describe these systems, including the sensors and the logic behind them. Here, the mechatronic model represents the next consistent level, in which the mechanical and electronic components are described including their logic and behaviour. This means that a mechatronic model can be used not only for planning, but also for commissioning, programming, monitoring and optimisation during production.

Just as equipment suppliers today provide the CAD data for their components and grippers, system integrators and customers would like to see corresponding mechatronic models that describe all relevant mechatronic properties in a uniform and compatible format. AutomationML (Automation Markup Language) is a neutral data format from the automotive industry that combines geometry, kinematics and logic in a standardised way. Just as HTML describes the structure of a web page with text, images and logic, AutomationML can describe the functional structure of individual assemblies, more complex systems and entire factories. The direct signal exchange can then ideally take place directly via the manufacturer-neutral OPC-UA interface. The combination of AutomationML and OPC-UA provides ready-to-use standards that offer maximum flexibility and a very wide range of possible applications. “Open Platform Communications Unified Architecture, OPC-UA for short, is a platform-independent, service-oriented architecture with the ability not only to transport machine data (controlled variables, measured values, parameters, etc.) but also to describe them semantically in a machine-readable way”. (Source: https://de.wikipedia.org/wiki/OPC_Unified_Architecture)

Conclusion

Economic pressure, hygienic requirements, indispensable, reliable documentation and traceability, sustainability and resource efficiency and, last but not least, the increasing shortage of skilled labour are the main factors that are also forcing the food industry to push ahead with the automation of its operations and production. If the topic of Industry 4.0 is also taken into account at the same time, there is no getting around the flexibility of the robots. This results in enormous future potential for robot manufacturers, but also for gripper developers and manufacturers. Although significant progress has been made in this regard in recent years, there is still considerable work to be done in the field of gripper development in order to be able to meet the diverse requirements of the various sectors of the food industry. In view of the many special features in the various sectors of the food industry, even closer cooperation with the competent gripper manufacturers would be welcome here, in order to further develop the grippers on the basis of concrete tasks and possibly also to formulate aspects that still need to be researched. Without question, the future development of grippers remains challenging and exciting!

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