BionicSoftHand
Pneumatic robot hand with artificial intelligence

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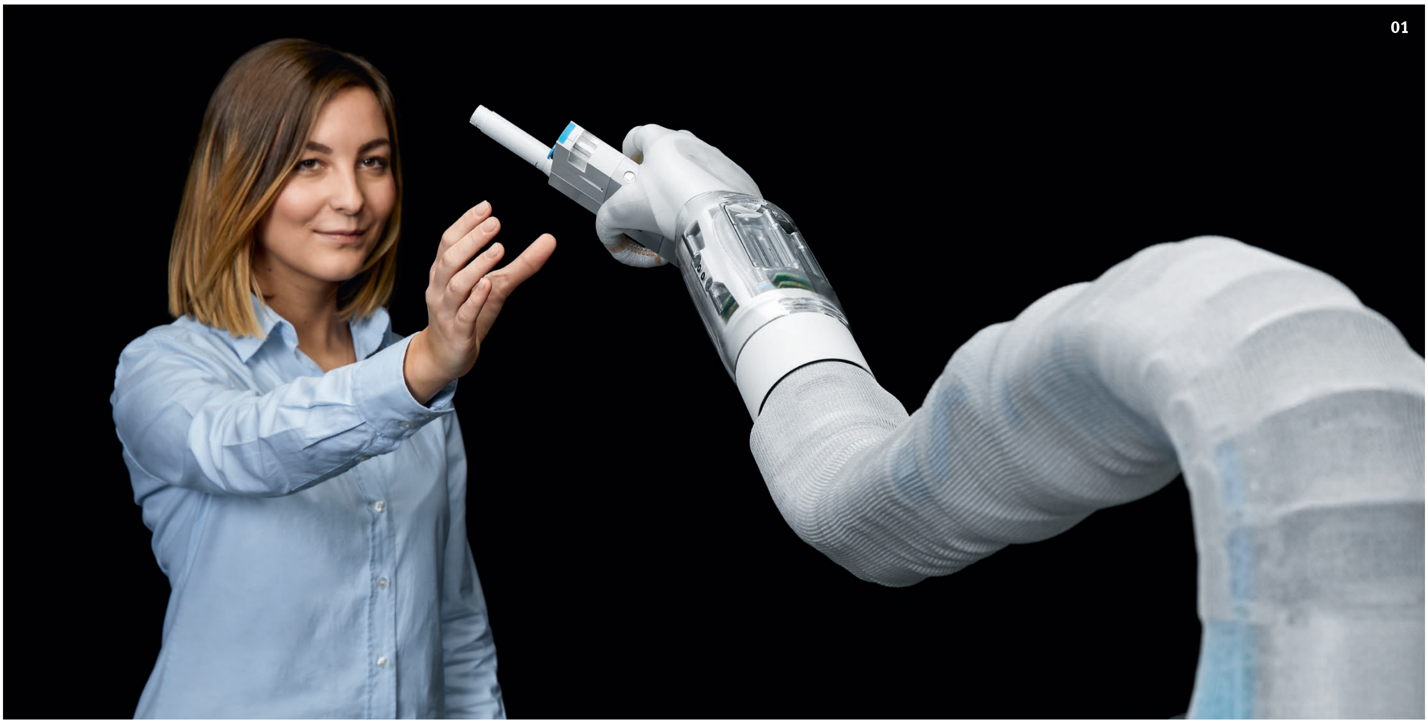
Pneumatic gripper based on the human hand



01

Whether grasping, holding or turning, touching, typing or pressing – in everyday life, we use our hands as a matter of course for the most diverse tasks. The human hand – with its unique combination of force, dexterity and fine motoric skills – is a true miracle tool of nature. An important role is played by the human thumb, which is positioned opposite the other fingers. This so-called opposability enables us, for example, to clench a fist, to grasp precisely and to also do filigree work.

Compliant kinematics for safe collaboration
What could be more logical than equipping robots in collaborative working spaces with a gripper that is modelled on this natural model and can learn through artificial intelligence to solve various tasks?

The BionicSoftHand is pneumatically operated so that it can interact safely and directly with people. Its gripper fingers consist of flexible bellows structures with air chambers and other soft materials. This makes it light, flexible, adaptable and sensitive, yet capable of exerting strong forces.

Functional integration in the tightest of spaces
In order to carry out the movements of the human hand realistically, small valve technology, sensor technology, electronics and mechanical components are integrated in the tightest of spaces.

Gripping and learning – intelligent interaction
By means of artificial intelligence, the bionic robot hand learns to independently solve gripping and turning tasks similarly to the human hand in interaction with the brain: our hands not only react to the commands of the brain but also simultaneously provide it with important information to adapt further actions to the environment and its requirements.

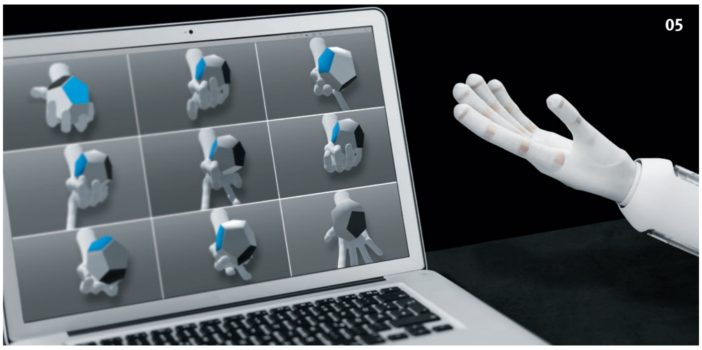
Neuroscientists say that humans are only so intelligent because the hand can solve so many complex tasks. Babies start to grasp very early – for example, the mother's finger. Once they have learned to grasp an object correctly, they can rotate it and look at it from all sides. This is the only way a 3D image of the object can be reconstructed in the head. Thus, the hand also helps humans to learn.

01: **Complete pneumatic system:** safe interaction with the BionicSoftHand on the BionicSoftArm

02: **Machine vision:** computer vision to collect the necessary data for a virtual image

03/04: **Digital twin:** the real robot hand and its virtual image in the simulation model

05: **Massively parallel learning:** fast learning through the duplication of the digital twin



Reinforcement learning: the principle of reward
The learning methods of machines are comparable to those of humans – be it positive or negative, they both need feedback on their actions in order to classify them and learn from them. BionicSoftHand uses the method of reinforcement learning, learning by strengthening.

This means that instead of having to imitate a concrete action, the pneumatic robot hand is merely given a goal. It tries to achieve this through trial and error. Based on the feedback received, the hand gradually optimises its actions until it finally solves the task successfully.

Digital twin of the real robot hand
Specifically, the BionicSoftHand should rotate a 12-sided cube so that a previously defined side points upwards at the end. The necessary movement strategy is taught in a virtual environment with the aid of a digital twin, which is created with the help of data from a depth-sensing camera via computer vision and the algorithms of artificial intelligence.

Fast knowledge transfer through massively parallel learning
The digital simulation model accelerates the training considerably, especially if you multiply it. In so-called massively parallel learning, the acquired knowledge is shared with all virtual hands, which then continue to work with the new state of knowledge: so each mistake is made only once. Successful actions are immediately available to all models.

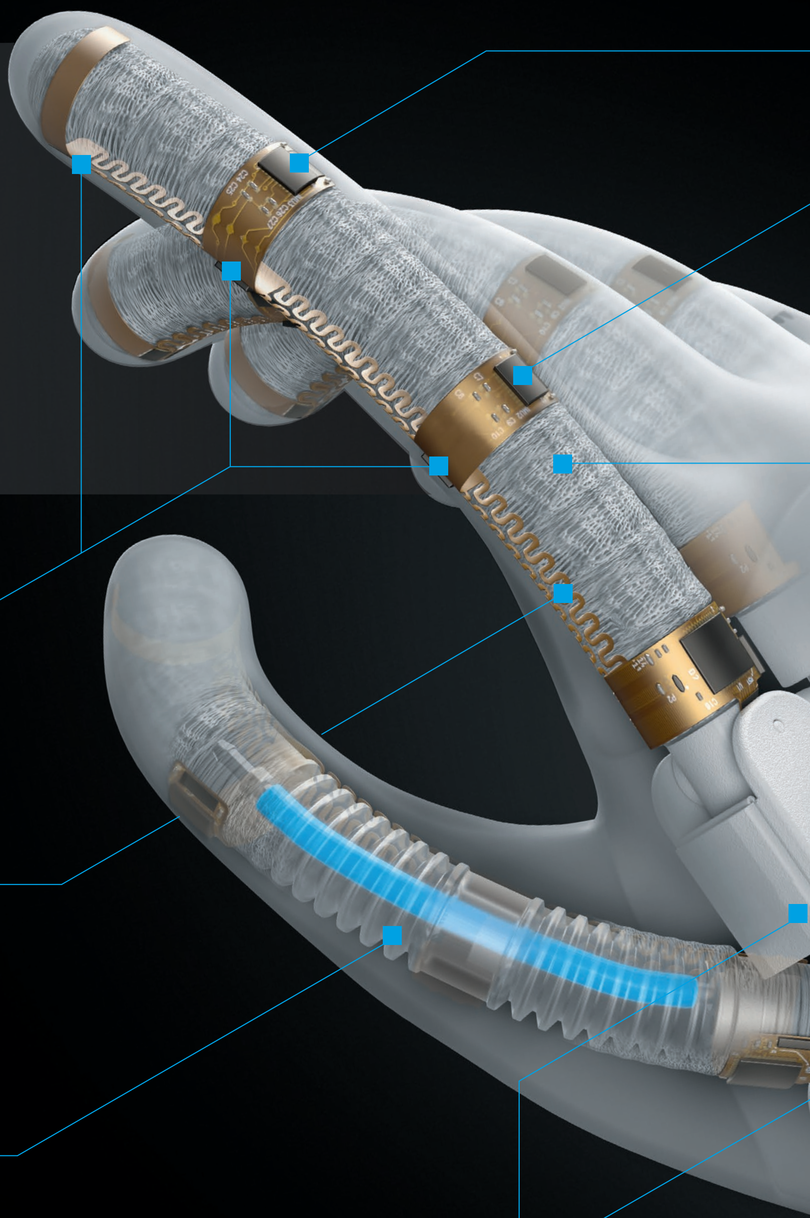
After the control has been trained in the simulation, it is transferred to the real BionicSoftHand. With the virtually learned movement strategy, it can turn the cube to the desired side and orient other objects accordingly in the future.

Learning algorithms instead of complex programming
In automation today, many tasks are too complex to be able to directly program every movement and function. Due to its many degrees of freedom, conventional control strategies are not readily applicable with the BionicSoftHand. In order to fully exploit its productivity and efficiency potential, it needs to learn on its own how to adapt its behaviour and, subsequently, expand its skills.

BionicSoftHand

Highly integrated soft robotic components

Unlike the human hand, the BionicSoftHand has no bones. It controls its movements via the pneumatic structures in its gripper fingers. When the chambers are filled with air, the gripper fingers bend. If the air chambers have been exhausted, the gripper fingers remain stretched. The thumb and index finger are additionally equipped with a swivel module which allows these two gripper fingers to be moved laterally. This gives the bionic robot hand a total of twelve degrees of freedom.



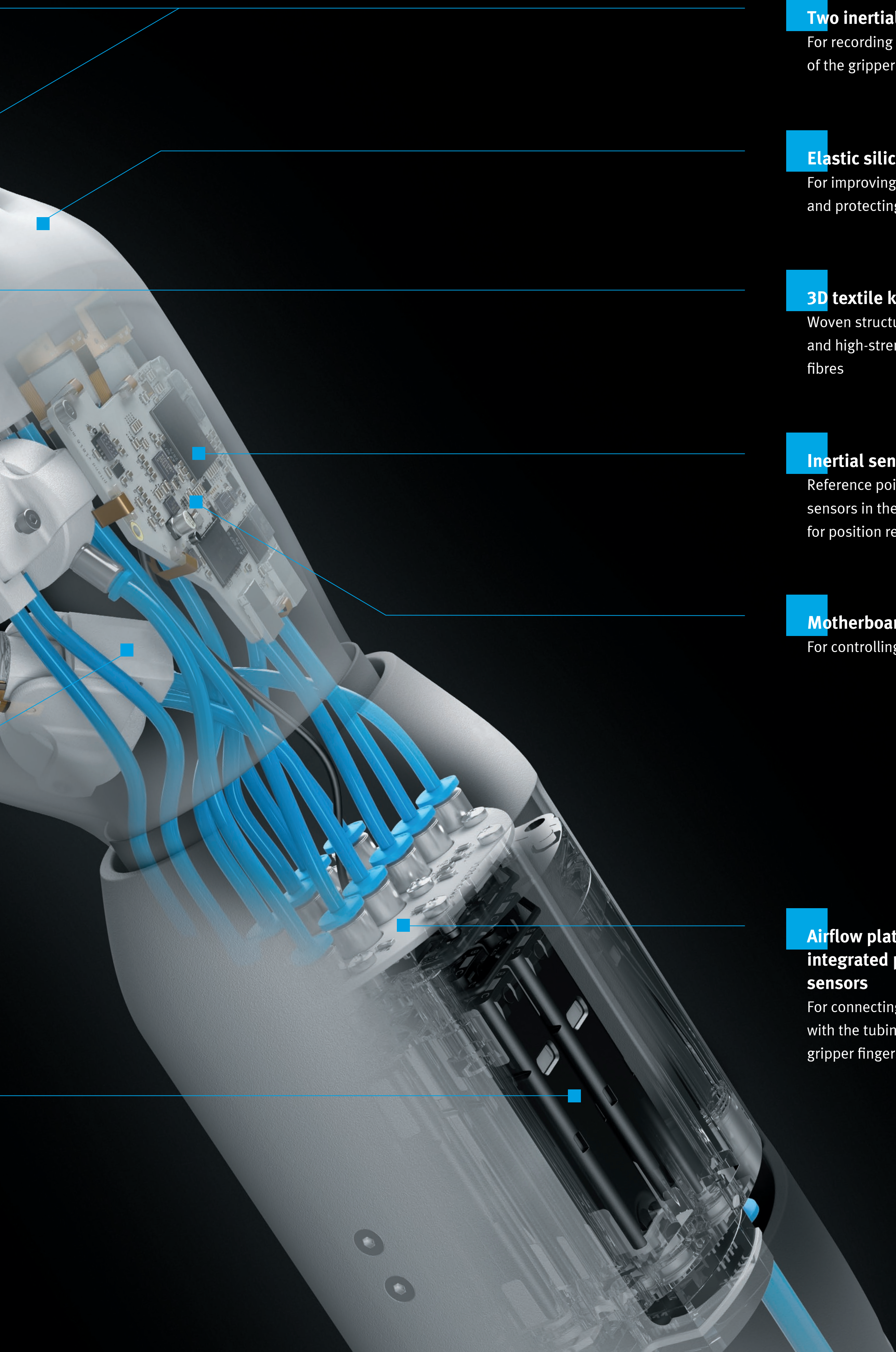
Three tactile force sensors
For measuring force and detecting different gripping objects

Flexible printed circuit board
With meander structure and integrated inertial and force sensors

Elastomer bellows
With two air chambers for moving the gripper fingers

Two pneumatic swivel modules
One additional degree of freedom for each lateral movement

Compact valve terminal
With 24 proportional piezo valves for precisely ventilating and exhausting the gripper fingers and controlling the swivel modules



Two inertial sensors
For recording the position of the gripper fingers

Elastic silicone skin
For improving the haptics and protecting the sensors

3D textile knitted fabric
Woven structure with elastic and high-strength synthetic fibres

Inertial sensor system
Reference point for the inertial sensors in the gripper fingers for position recognition

Motherboard
For controlling the hand

Airflow plate with integrated pressure sensors
For connecting the valves with the tubing of the gripper fingers

BionicSoftHand

Sensitive robot hand with digital control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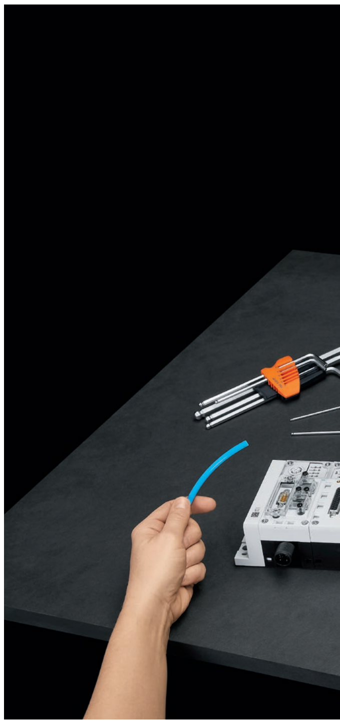


In order to keep the effort of tubing the BionicSoftHand as low as possible, the developers have specially designed a small, digitally controlled valve terminal, which is mounted directly on the hand. This means that the tubes for controlling the gripper fingers do not have to be pulled through the entire robot arm. Thus, the BionicSoftHand can be quickly and easily connected and operated with only one tube each for supply air and exhaust air.

Proportional piezo valves for precise control

The valve terminal consists of 24 proportional piezo valves with which the flow rates and pressures in the gripper fingers of the robot hand can be precisely dispensed. That enables both forceful and sensitive motion sequences.

The 24 valve nozzles are connected via an airflow plate to the ten air connections of the gripper fingers and the two swivel modules. At the same time, the pressure sensors required for precise control are located on the plate. In order to be able to realise the filigree design with the complex air ducts in such a tight space, the plate is produced with 3D printing.

Pneumatic kinematics with 3D textile knitted fabric

The gripper fingers are moved over a bellows made of robust elastomer with two chambers, which are pressurised with compressed air. This makes them particularly elastic and hard-wearing at the same time. When both air chambers are completely empty, there is no force in the gripper fingers, and they remain stretched.

The rubber bellows are enclosed in a special 3D textile cover which is knitted from both elastic and high-strength fibres. This means that the textile can be used to exactly determine at which points the structure expands, thereby generating force, and where it is prevented from expanding. Because the outside of the gripper fingers is elastic, a strap is used to limit the longitudinal expansion on the inside of the gripper fingers. This way, the gripper finger bends as soon as it is filled with air.

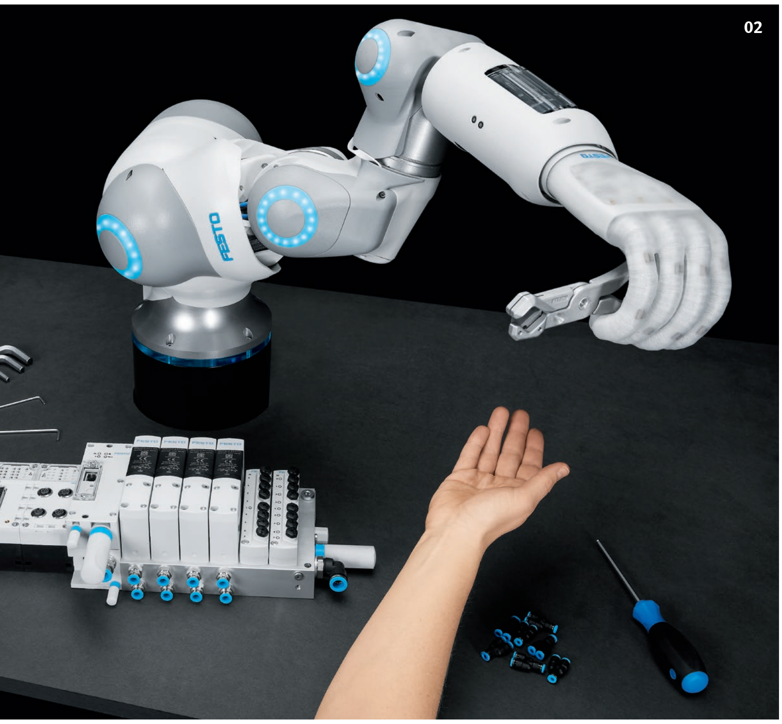
Flexible printed circuit boards with a meander structure are applied to the knitted fabric on which the inertial and tactile force sensors are located. The wafer-thin printed circuit boards are flexible and do not impair the movements of the gripper fingers.

01: **Easy commissioning:** quick connection to various lightweight robots, such as the BionicSoftArm

02: **Helping hand:** predestined for direct collaboration in collaborative spaces

03: **Versatile usage:** four BionicSoftHand pneumatic fingers in an adaptive pincer gripper

04: **Conceivable future scenario:** working from a safe distance by means of gesture imitation



Modular robot hand
Its flexible, pneumatic kinematics and the use of elastic materials and lightweight components distinguish the BionicSoftHand from electric or cable-operated robot hands and make inexpensive production possible. Thanks to its modular design, gripper variants with three or four pneumatic gripper fingers are also possible – for example, an adaptive pincer gripper.

Potential for human–robot collaboration
In combination with pneumatic lightweight robots, such as the BionicCobot or the BionicSoftArm, direct and safe human–robot collaboration is possible. Both robots are completely compliant and do not have to be shielded from the worker like conventional factory robots.

The BionicSoftHand is therefore predestined for applications in the collaborative working spaces of tomorrow's factories. Since the flexible robot hand can grip both strongly and sensitively, it can conceivably be used in assembly as a helping third hand and also in service robotics.

Remote manipulation by means of gesture imitation
Remote manipulation of the BionicSoftHand is also conceivable. With the help of images from a depth-sensing camera, the robot hand can imitate the gestures and hand movements of the user and react to them. The robot can thus be controlled from a safe distance, for example, when handling hazardous substances or carrying out processes that are harmful to health. In addition, several systems could be controlled simultaneously.

In production of the future, there will be a need for more flexible installations and components which are independently adjusted to the respective product being made. Adaptable grippers like the BionicSoftHand can assume a significant role in this respect.

Learned knowledge building blocks applicable worldwide
The ability to develop independent solution strategies will make the interaction between human and machine even more intuitive, simpler and more efficient in the future. Knowledge building blocks and new skills, once learned, can be limitlessly shared and made available on a global scale.

Technical data

- Length of gripper fingers: . . . . 4 × 98 mm
  . . . . 1 × 79 mm (small gripper finger)
- Degrees of freedom of the hand: 12
- Operating pressure: . . . . 3.5 bar (gripper fingers)
  . . . . 6.0 bar (swivel modules)
- Maximum load capacity: . . . . Up to 4 kg (depending on orientation)

Material:

- Skin:. . . . . Silicone
- Textile fabric:. . . . . Dyneema®
- Bellows:. . . . . EPDM with shore hardness of ~45
- Housing: . . . . 3D printing material
- Airflow plate:. . . . . Resin, produced in the stereolithography process

Sensor technology:

- 1 inertial sensor in the back of the hand
- 10 inertial sensors in the gripper fingers
- 15 tactile force sensors in the gripper fingers
- 14 pressure sensors in the airflow plate

- Pneumatic drives: . . . . 2 EV swivel modules
- Valve technology: . . . . 12 piezo cartridges from the Festo Motion Terminal VTEM

- Computer vision: 1 Leap Motion depth-sensing camera

- Dyneema® is a registered trademark of DSM IP Assets B.V., Heerlen, Netherlands

Project participants

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