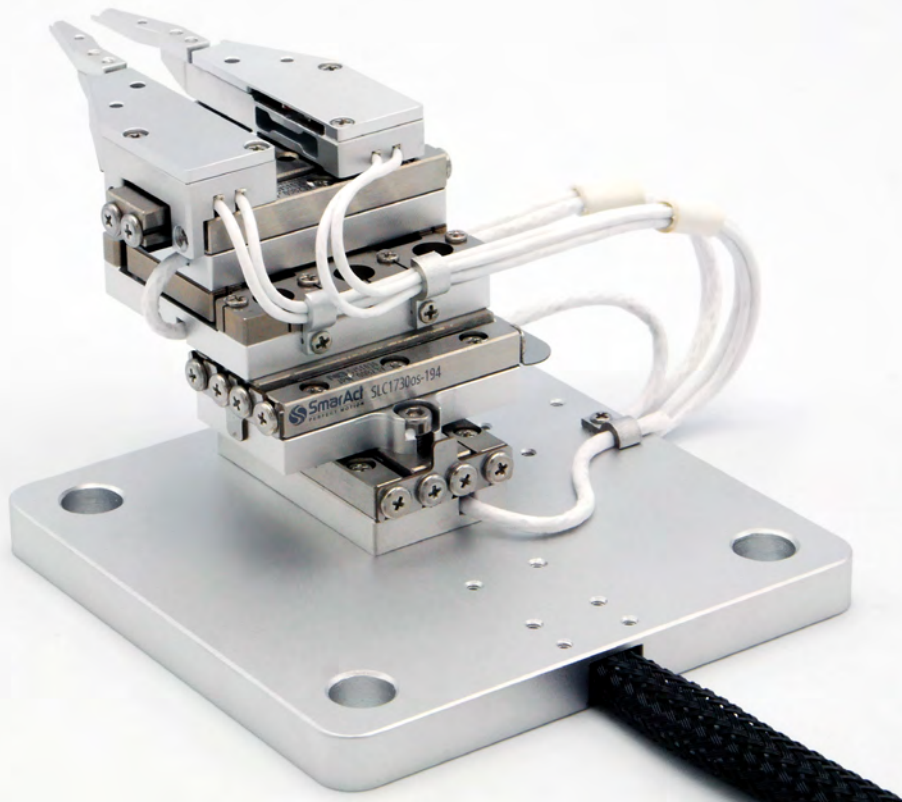


SMARBOTIC®

INTRODUCTION



SMARBOTIC®: High-Precision Robotic Systems from SmarAct

In the realm of precision engineering, SmarAct has established itself as a leader in high-precision robotic systems, offering cutting-edge solutions for industries that demand extreme accuracy. Specializing in micro- and nanopositioning technologies, these **SMARBOTIC** systems play a crucial role in scientific research, semiconductor manufacturing, and other nanotechnology applications.

One of the defining features of **SMARBOTIC** systems is our piezo-based drive technology. This technology enables ultra-precise movement with resolutions down to the nanometer scale, ensuring exceptional accuracy and repeatability. Unlike conventional motor-driven systems, SmarAct's solutions eliminate backlash and mechanical wear, resulting in higher durability and stability, which are essential for applications requiring long-term reliability.

SMARBOTIC systems are widely used in microscopy, optical alignment, and quantum technology, where precision is paramount. Their compact and modular design allows for seamless integration into various setups, making them ideal for both industrial and research environments. Additionally, these systems can be customized to meet specific application requirements, further enhancing their versatility and performance.

As part of our technical excellence, we are also focusing on user-friendly control interfaces, allowing for intuitive operation and seamless automation. SmarAct software solutions provide real-time feedback and advanced motion control, making it easier for customers to execute complex positioning tasks with minimal effort.

Comparison of Parallel and Serial Kinematics in Microrobotics

SMARBOTIC systems employ both parallel and serial kinematic structures, each offering unique advantages depending on the application.

Parallel Kinematics:

- In parallel kinematic systems, multiple actuators control a single moving platform, leading to high stiffness and precision.
- These systems are known for their high dynamic performance and ability to distribute forces efficiently, minimizing errors.
- They provide better stability and increased load capacity due to their symmetrical force distribution.
- However, they often have a more complex control system and a limited range of motion compared to serial kinematics.

Serial Kinematics:

- In serial kinematic systems, actuators are arranged in a sequential manner, with each actuator supporting the next.
- These systems offer a larger workspace and greater flexibility in motion due to their extended degrees of freedom.
- They are easier to control and program but may suffer from lower stiffness and accumulated positioning errors from multiple joints.
- Serial kinematics is more commonly used in applications requiring long travel ranges.

Both parallel and serial kinematics play a significant role in microrobotics, with the choice depending on the specific requirements of precision, stability, and range of motion. **SMARBOTIC** continues to innovate in both domains, ensuring tailored solutions for various high-precision applications while providing the following advantages and key features:

Versatile and Modular

SMARBOTIC systems combine linear, rotational and goniometric axes in a modular way leading to serial, parallel or hybrid kinematic motion systems with multiple degrees of freedom and allowing for rapid integration into customer setups.

Highly Customizable

In addition to our standard systems, **SMARBOTIC** systems can be tailored to your applications and will be designed by our experts according to your specifications. Benefit from our experience in the development of special systems for many well-known customers.

Mounting Options

The **SMARBOTIC** motion systems can be mounted in horizontal or up-side down orientation. Please mention the planned mounting orientation in your application when contacting us. We will help to find or adjust the **SMARBOTIC** motion system to realize the desired mounting configuration.

High Resolution and Closed-Loop Control

SMARBOTIC systems feature a backlash-free mechanical design and closed-loop control that enables nanometer-scale motion performance and high repeatability.

Compact Design

SMARBOTIC systems are designed in the most compact way to realize smallest footprints while providing maximum travel ranges.

Vacuum Compatibility and Non-Magnetic Materials

Most **SMARBOTIC** systems are available as vacuum-capable versions up to 10^{-11} mbar and as non-magnetic versions.

On the following pages, this brochure provides an overview of possible solutions for multi-dimensional positioning projects:

With our **SMARPOD** and **TRIPOD** product family we offer hybrid kinematic systems for various applications. In addition, our modular systems allow for a flexible combination of serial kinematic setups.

For more complex micro- and nanomanipulation tasks we also provide a variety of microgrippers with different and exchangeable gripper jaws as well as force sensing capabilities.

Control in Cartesian Coordinates

Calculation of the kinematics model and device control is encapsulated in a software package. Programming interfaces and graphical user interfaces allow the **SMARBOTIC** motion systems to move in Cartesian coordinates (X, Y, Z, Rx, Ry, Rz).

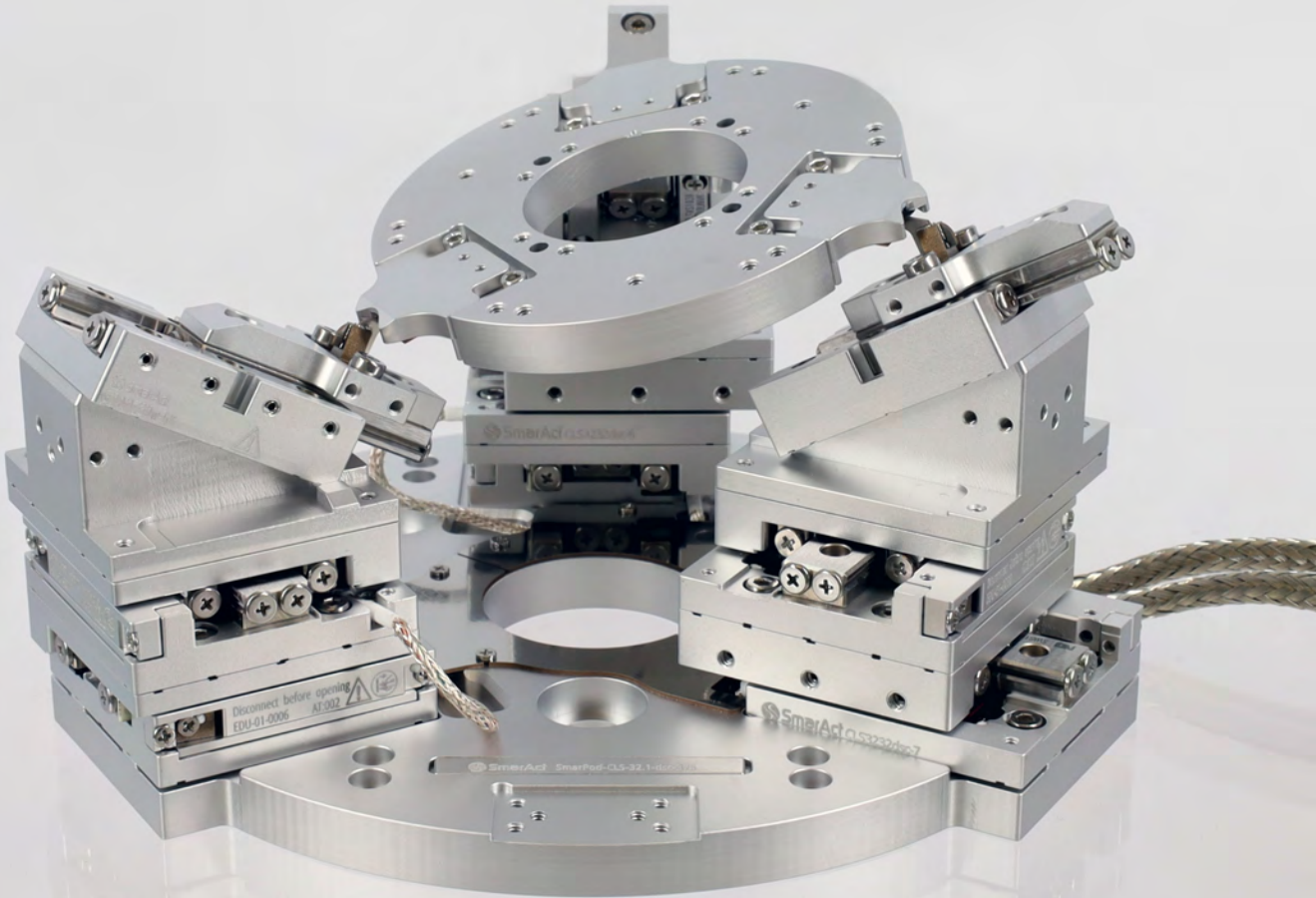
User-Definable Pivot Point and Axis Alignment

One great advantage is the possibility to freely set the rotations' pivot point. By defining the center of rotation, the **SMARBOTIC** motion systems can precisely rotate around any addressable point in space. In addition, the base coordinate system can be shifted and rotated to be aligned in customer or application specific environments.

Our controller architecture is now completed by a new version of the Embedded Control Module (ECM) empowering real motion control for our complex motion systems along interpolated trajectories with high path accuracy.

A new control software will allow for easy integration and operation of all SmarAct positioners and systems. Especially for robotic and complex applications, the software will provide intuitive user interfaces and low-code application development.

SMARBOTIC® SMARPOD®

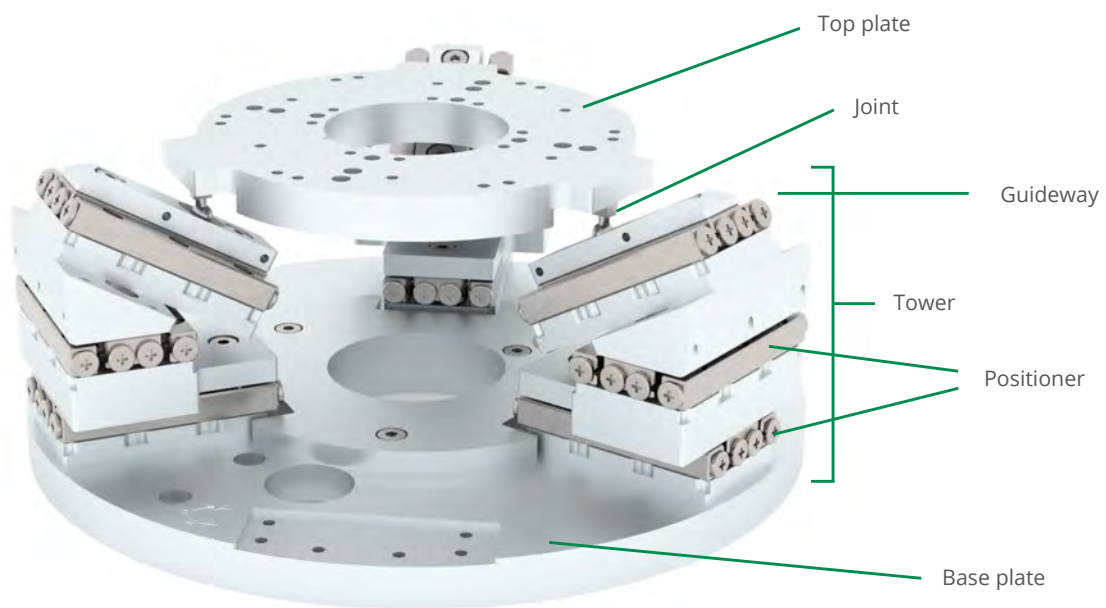


SMARPOD®: Hexapod-like Systems with 6 Degrees of Freedom

SMARPOD motion systems offer six degrees of freedom similar to classical hexapod systems while guaranteeing highest resolution and repeatability. A user-friendly software package allows easy integration into your own control environment assuring a very short setup time.

Working Principle

The SMARPOD is a parallel kinematics robotic system, where the top plate is actuated by the simultaneous movement of multiple linear SMARSLIDE® stages. Three towers, each combining two actuated stages (radial and tangential) and a passive guideway, are connected to the top plate by joints. The parallel arrangement of the SMARPOD's positioners contributes to the overall stiffness of the system and allows the top plate to be translated and rotated in six degrees of freedom.



All SMARPODs with circular base plates include an aperture in the base and top plate. These apertures allow access from beneath the positioning system to electrically connect the sample or to get optical access to mounted components.

In addition to our customer-specific solutions, the following standard SMARPOD models are available.



	70.42	110.45	CLS-32	225.75	225.75 HL	P-SLC-17	P-SLC-24	P-CLL-CLS	
Mechanical	Travel X [mm]	11	20	42	42	50	102*	330*	
	Travel Y [mm]	11	20	42	42	30*	62*	65*	
	Travel Z [mm]	6	11	24	7	10	17		
	Rotation Θ_x [°]**	22	23	22	24	7	25	33	32
	Rotation Θ_y [°]**	23	26	25	27	8	22	33	34
	Rotation Θ_z [°]**	31	38		41		16	36	30
	Max. Normal Force [N]	5			40		4	5	4
	Max. Horizontal Force [N]	2.5					2	2.5	2
	Dimensions Base Plate [mm]****	Ø 70	Ø 110	Ø 123.7	Ø 225		110 x 70	195 x 91	554 x 45
	Height above Ground [mm]	42	45	54.5	75		67.4	81	72
Weight [g]	200	410	520	2060		680	1890	2950	
Closed-Loop	Smallest Increment [nm]	1							
	Smallest Increment [μ°]	3							
	Uni-Directional Repeatability MCS2 [nm] ***	± 50						± 100	
Options	Vacuum	HV (10^{-6} mbar); UHV 10^{-11} mbar)							
	Non-Magnetic	--	yes (-NM)					no	
	Orientation	0°/180°			0°	--	0°		
	Material	on request							
	Additional Mounting Posts	--	yes			no			
	High Stiffness	--	yes		included	yes		included	
	Alternative Travel	--			on request				
	High-Load	-	yes		included	yes			

* Other travels upon request.

** Values given for a Pivot point at the surface of the top plate.

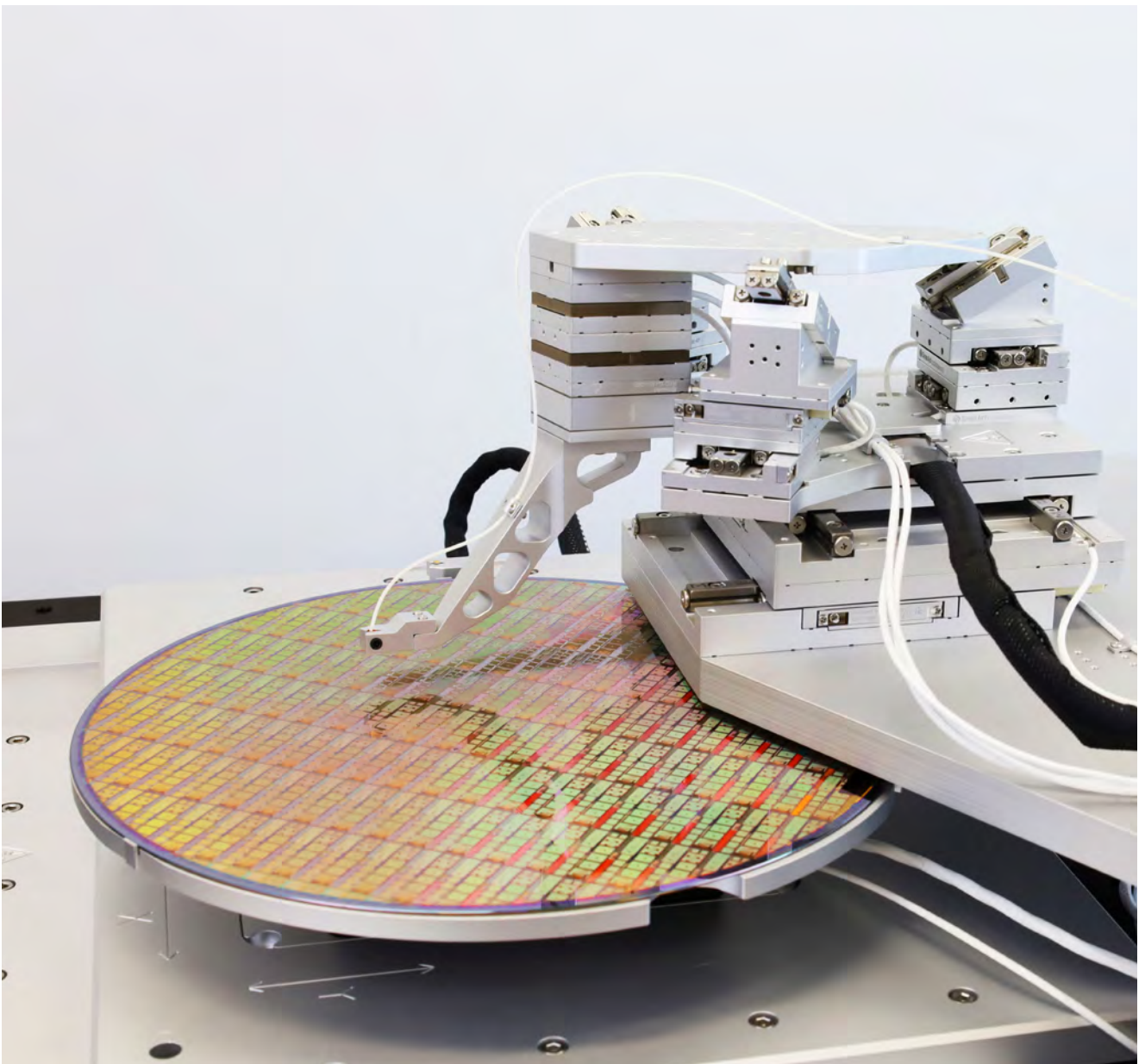
*** Measured at 20 mm above the top plate, over the full range and for each dimension separately. An improvement can be expected for shorter travel ranges.

**** Total dimensions of the overall system might be larger for different poses. Compare CAD model for further information

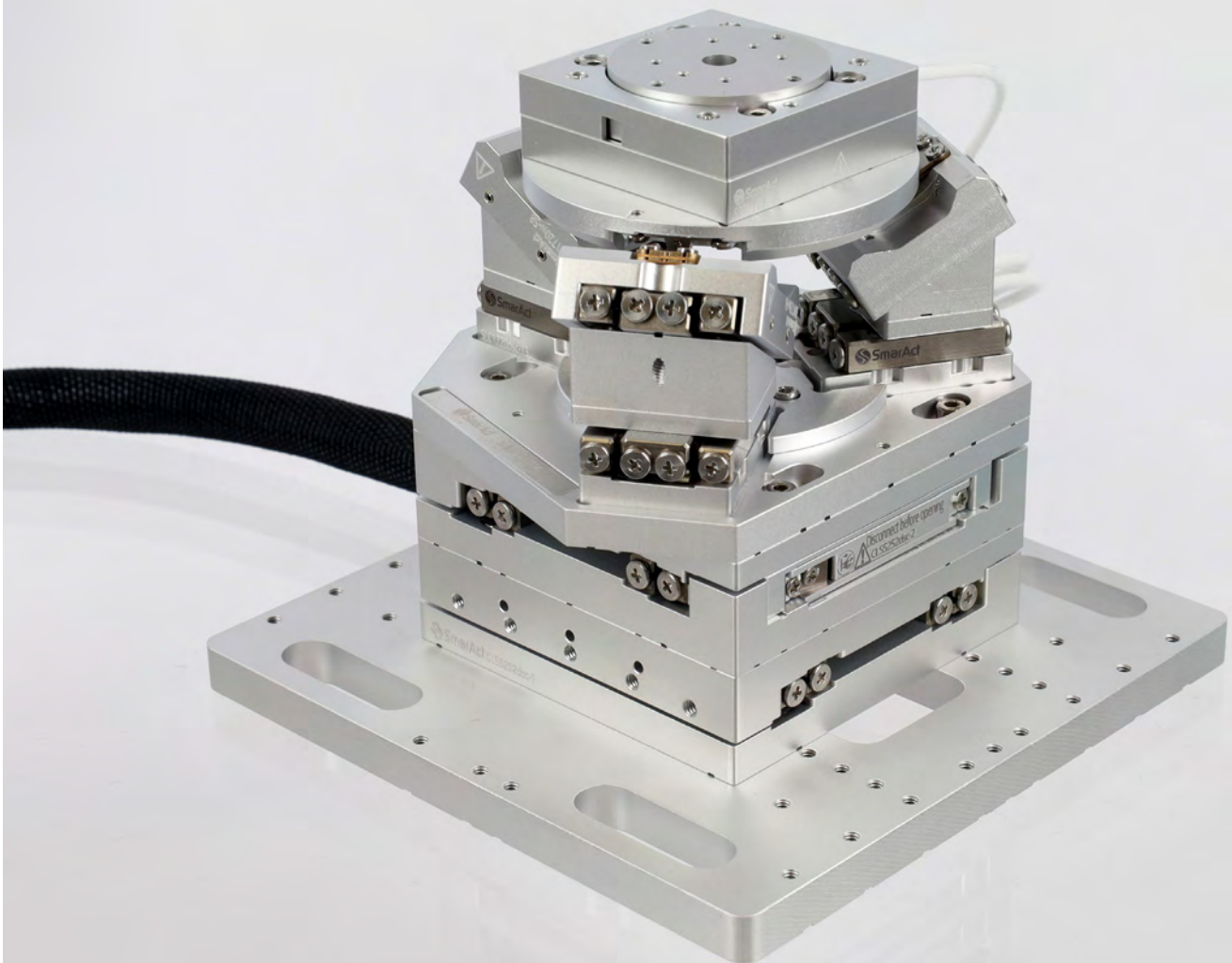
Application Example: Fiber Alignment for Photonic Integrated Circuits

Photonic Integrated Circuits (PICs) have great potential to drive the steady performance increase in information processing. PICs have advantages when it comes to higher density, higher speed, and improved power efficiency. Especially silicon photonics allows for a high level of integration by fabricating PICs with conventional semiconductor manufacturing techniques. The combination of different SmarAct Motion technologies is the key for a versatile system that enables fast and accurate alignment of fibers to PICs at wafer and die level. For example, **SMARSHIFT**[®] electromagnetic direct drives combine speed, force and nm accuracy and

can move wafers in up to six degrees of freedom. **SMARPODS** bring fibers in position via coarse alignment to couple light into and out of the wafer. Additional XY motion in a square of 60mm x 60mm is provided by **SMARSLIDE**[®] stages. The actual fine-alignment is performed by a **SMARFLEX**[®] XYZ piezo scanner stack, ideally combining the requirements of nm resolution and high speed. To minimize the coupling speed, the **MCS2** controller includes algorithms that perform different scan movements and optimization routines which are based on the measured light power.

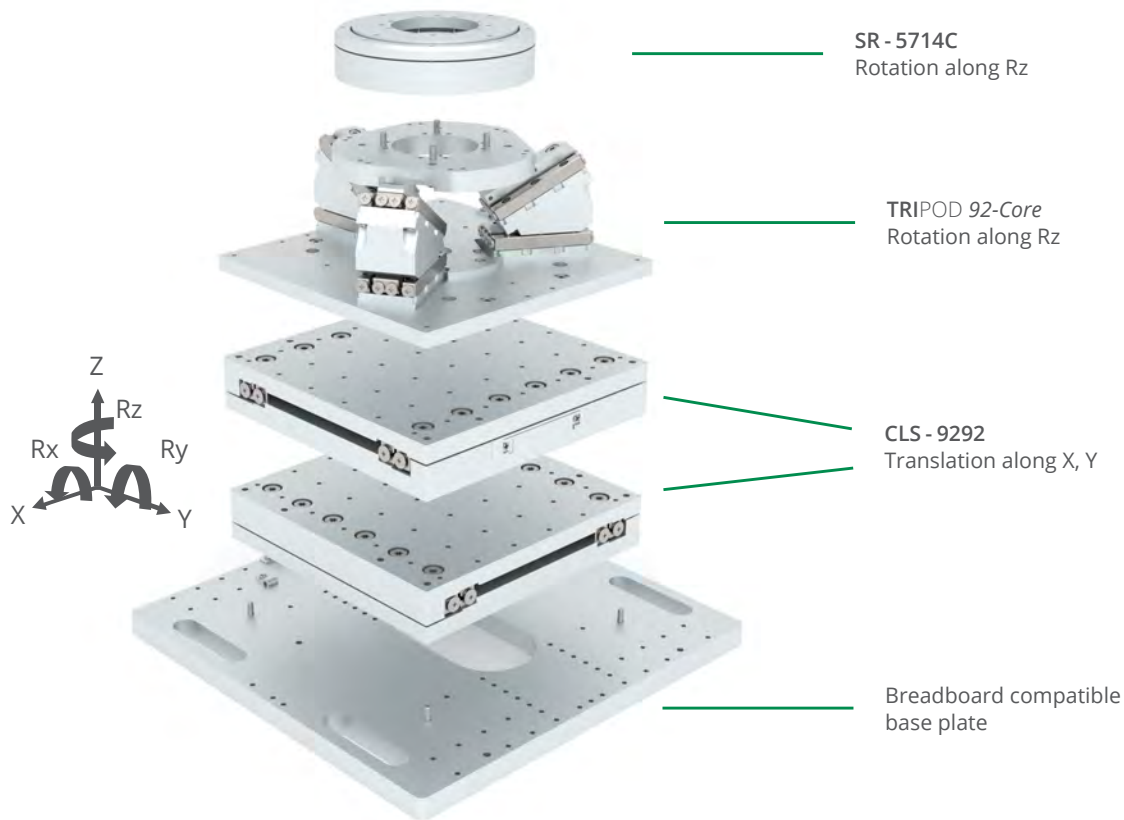


SMARBOTIC® TRIPOD



TRIPOD: Hexapod-like Systems from 3 up to 6 Degrees of Freedom

The TRIPOD product series offers highly modular multidimensional positioning systems that combine the versatility of serial kinematics and the compactness of parallel kinematics in one hybrid design.



TRIPOD 92-6DoF

Based on the SmarAct Modular System, multiple combinations of SmarAct positioning products allow us to realize versatile and highly precise motion systems. The standard TRIPOD family consists of systems that employ **SMARSLIDE**[®] piezo positioners, such as the TRIPOD 52 or TRIPOD 92 or **SMARSHIFT**[®] electromagnetic direct drives such as the TRIPOD 400.

The TRIPOD 52-Core and TRIPOD 92-Core are three-dimensional tip-tilt parallel kinematic systems and are the central components of the TRIPOD 52 and TRIPOD 92 series. They offer two rotational (Rx, Ry) and one translational (Z) degree of freedom and are fully compatible with the SmarAct Modular System. Placing the TRIPOD Core on top of a high-precision XY platform, based on either **SMARSLIDE** CLS-52

or CLS-92 positioners, gives the basic design of a TRIPOD 52-5DoF and TRIPOD 92-5DoF motion systems. These offer three translational (X, Y, Z) and two rotational (Rx, Ry) degrees of freedom. Due to their hybrid system design, combining parallel and serial kinematics, the translation in the XY plane does not affect the remaining degrees of freedom in Z, Rx and Ry, resulting in a larger working range.

The TRIPOD 52-6DoF and TRIPOD 92-6DoF add an additional rotation stage on the top plate of the TRIPOD -5DoF systems, thus creating modular positioning systems with six degrees of freedom that allow a continuous rotation around the Z-axis.



TRIPOD 400-6DoF

The newest member of the **SMARBOTIC® TRIPOD** family is the **TRIPOD 400-6DoF**. It fully relies on the **SMARSHIFT** electromagnetic direct drives. The **TRIPOD 400-Core** consists of three **MLS-92122** and is placed on top of an **MLL-400 XY** platform. On the top plate, an **MR-30028** is positioned to allow motion in three translational and three rotational degrees of freedom. The **TRIPOD 400-6DoF** is

designed to offer the largest travel ranges in the **XY** plane from all **TRIPOD** systems and in addition shows the best dynamic performance due to the usage of electromagnetic direct drives. This system can carry the largest load of all **TRIPOD** systems by implementing force compensation and pneumatic brakes.



TRIPOD 52-6DoF



TRIPOD 92-6DoF



TRIPOD 400-6DoF

		TRIPOD 52-6DoF	TRIPOD 92-6DoF	TRIPOD 400-6DoF
Mechanical	Travel [mm]	31 (X); 31 (Y); 6 (Z)	63 (X); 63 (Y); 11 (Z)	200 (X); 200 (Y); 16 (Z)
	Rotation [°]*	20 (Θx); 19 (Θy); 360 (Θz)	31 (Θx); 27 (Θy); 360 (Θz)	6 (Θx); 7 (Θy); ≥ 360 (Θz)
	Max. Normal Force [N]	3		60
	Max. Horizontal Force [N]	2.5	1.75	Not allowed
	Dimensions Base Plate [mm]***	90 x 90	142 x 142	400 x 400
	Height above Ground [mm]	79.5	94.4	183
	Weight [g]	490	1430	31000
Closed-Loop	Smallest Increment [nm]	1		1
	Smallest Increment [μ°]	3		3
	Uni-Directional Repeatability MCS2 [nm]**	± 50		± 100(X,Y); ± 25(Z)
Options	Vacuum	HV (10 ⁻⁶ mbar); UHV (10 ⁻¹¹ mbar)		No
	Non-Magnetic	No	Yes	No
	Orientation	On request		0°/180°
	Material	On request		
	Alternative Travel	On request		
	Aperture	On request		
	High Stiffness	No	Yes	No

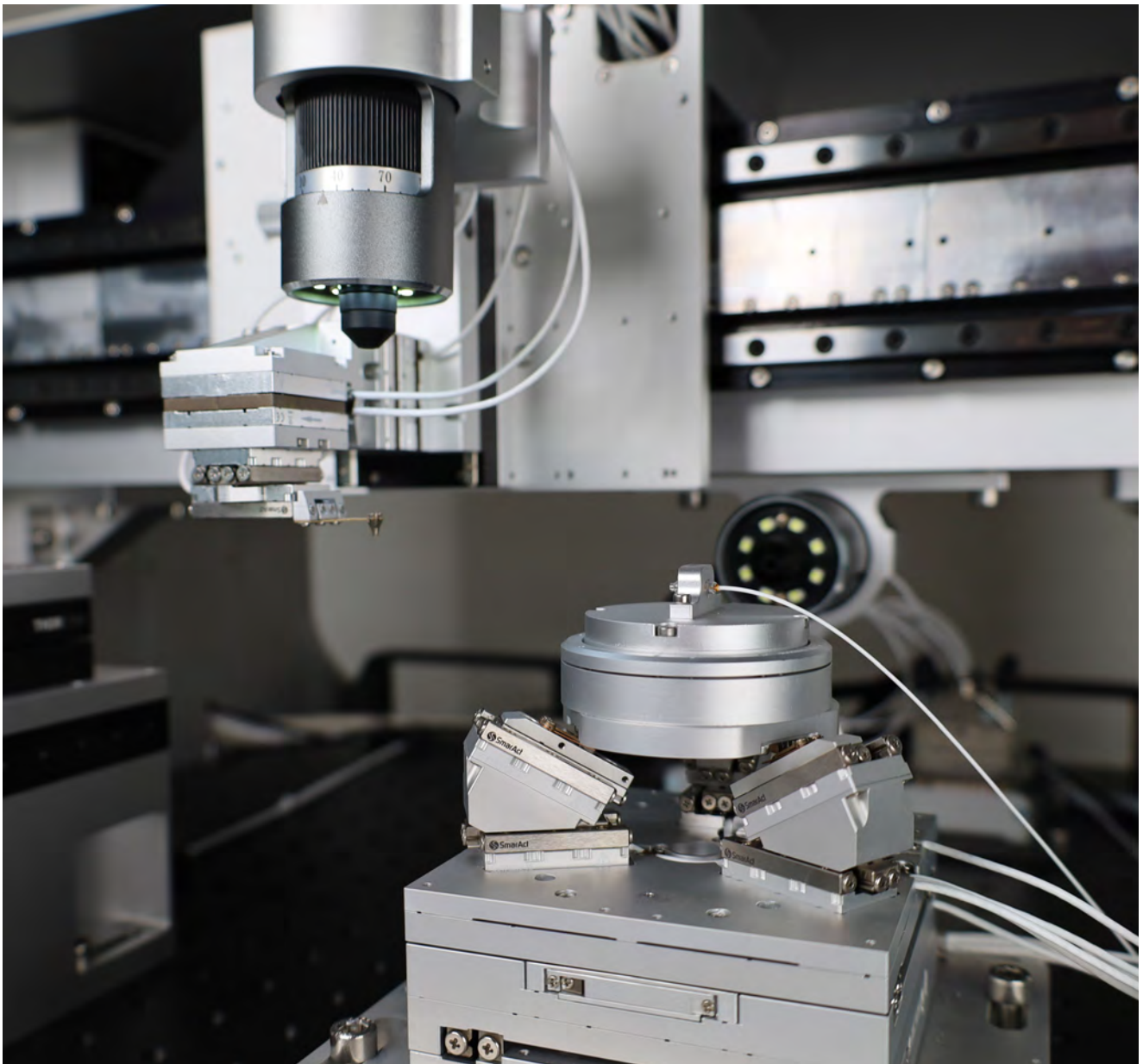
* Values given for a Pivot point at the surface of the top plate.

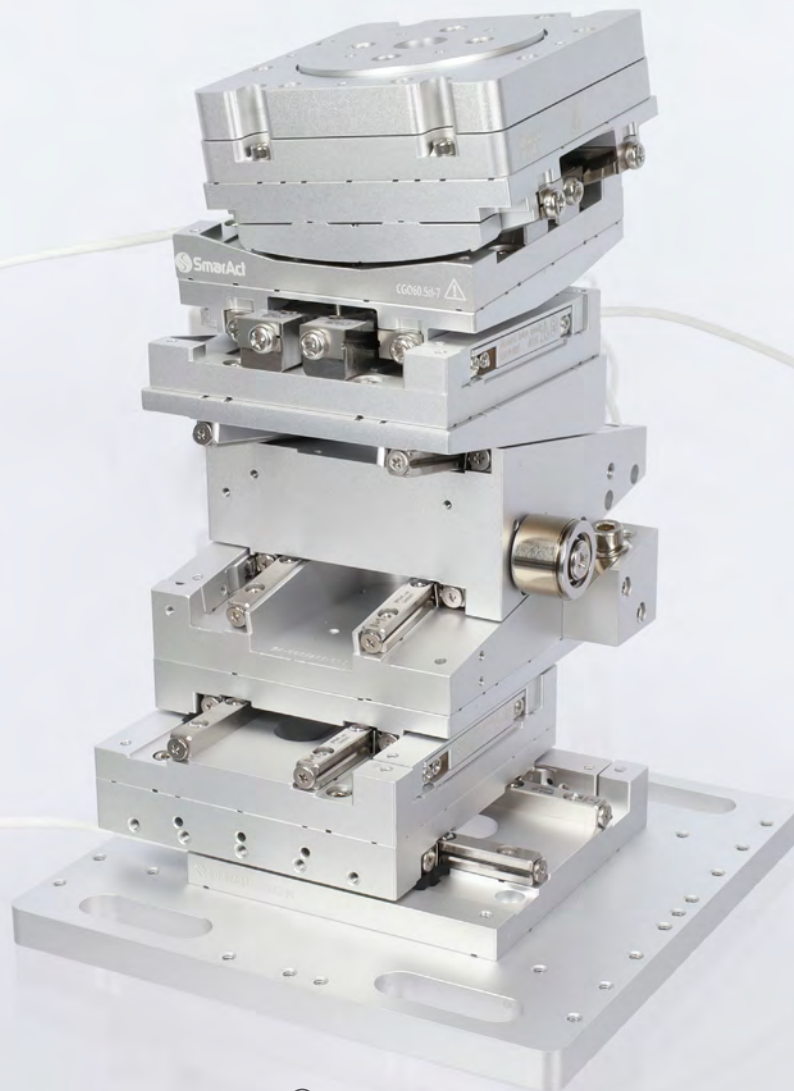
** Measured at 20 mm above the top plate, over the full range and for each dimension separately. And improvement can be expected for shorter travel ranges.

Application Example: Alignment and Microassembly of Optical Components

In the realm of precision engineering, the alignment and microassembly of small optical components are crucial for ensuring optimal performance and reliability in various high-tech applications. SmarAct advanced positioning systems provide the precision and stability required for these demanding tasks, addressing the growing need for miniaturized optical systems in telecommunications, medical devices, and scientific research.

A prime example of SmarAct's capabilities is the combination of a pick-and-place task with an alignment process for a 2 mm beam splitter cube. This process involves picking up the cube from a sorting tray and transferring it to an optical fiber. The cube and the fiber are then precisely aligned with each other by using a **SMARBOTIC® TRIPOD** system. This step is essential for quality control or the initial stage in a microassembly process, during which the cube is glued to the fiber after alignment.





SMARBOTIC® MODULAR SYSTEM

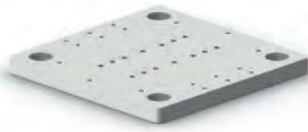
Modular Systems: Flexible and Convertible Positioning-Systems from One or More Degrees of Freedom

Change is a constant in academic research as well as in industrial manufacturing. Equipment needs to be adaptable in order to address new requirements and to keep investments manageable.

The **SMARBOTIC** modular system is a product concept which allows customers to adapt, modify and reconfigure even complex multi-axis positioning systems in the field, based on stringent modularity and compatibility between linear, rotation and goniometer stages.

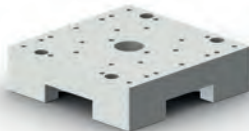
It allows the combination of compatible stages of the CLS, SLC, CGO, DLS, MLS, PLF and SR product series to form complex and reconfigurable positioning setups. Standardized angle brackets, adapters and accessories provide the flexibility needed to combine SmarAct's single-axis stages into convertible instruments while guaranteeing the highest precision and quality of the positioning solution thus created.

Mounting Accessories



Breadboard Adapters and Base Plates

Several breadboard adapters are available to fix the positioning system onto your existing optical table or breadboard based experimental setup. The product portfolio includes adapters of different sizes and shapes perfectly matching the corresponding linear stages of the SLC and CLS series. The mounting hole pattern of the adapters allows mounting of linear and rotation stages of different sizes while also providing anchoring points for cable management clamps.



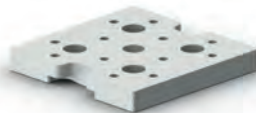
Spacer

Spacers have the same outer dimensions as the corresponding linear stages. They can be mounted directly onto breadboard adapters, on top of stages and on top of each other.



Brackets

Brackets allow vertical mounting of linear, rotation or goniometer stages to other stages or directly onto the breadboard adapters. Several different dimensions are available to allow mounting of SLC and CLS linear stages, SR rotation stages as well as CGO goniometer stages of different sizes.



Adapter Plates and Clamps

Adapter plates and clamps are required when stacking linear stages or when mounting right-angled brackets or rotation stages. The shape of the clamp depends on the length and the mounting hole pattern of the linear stages used. There are clamps for mounting right-angled brackets on linear stages or for mounting two linear stages perpendicular to each other.



Constant Force Springs

Constant force spring assemblies compensate for static loads on stages when used in vertical orientation. Each assembly includes an adapter that attaches to the bracket as the anchor point for the spring and an adapter plate that mounts to the front of the vertical stage.



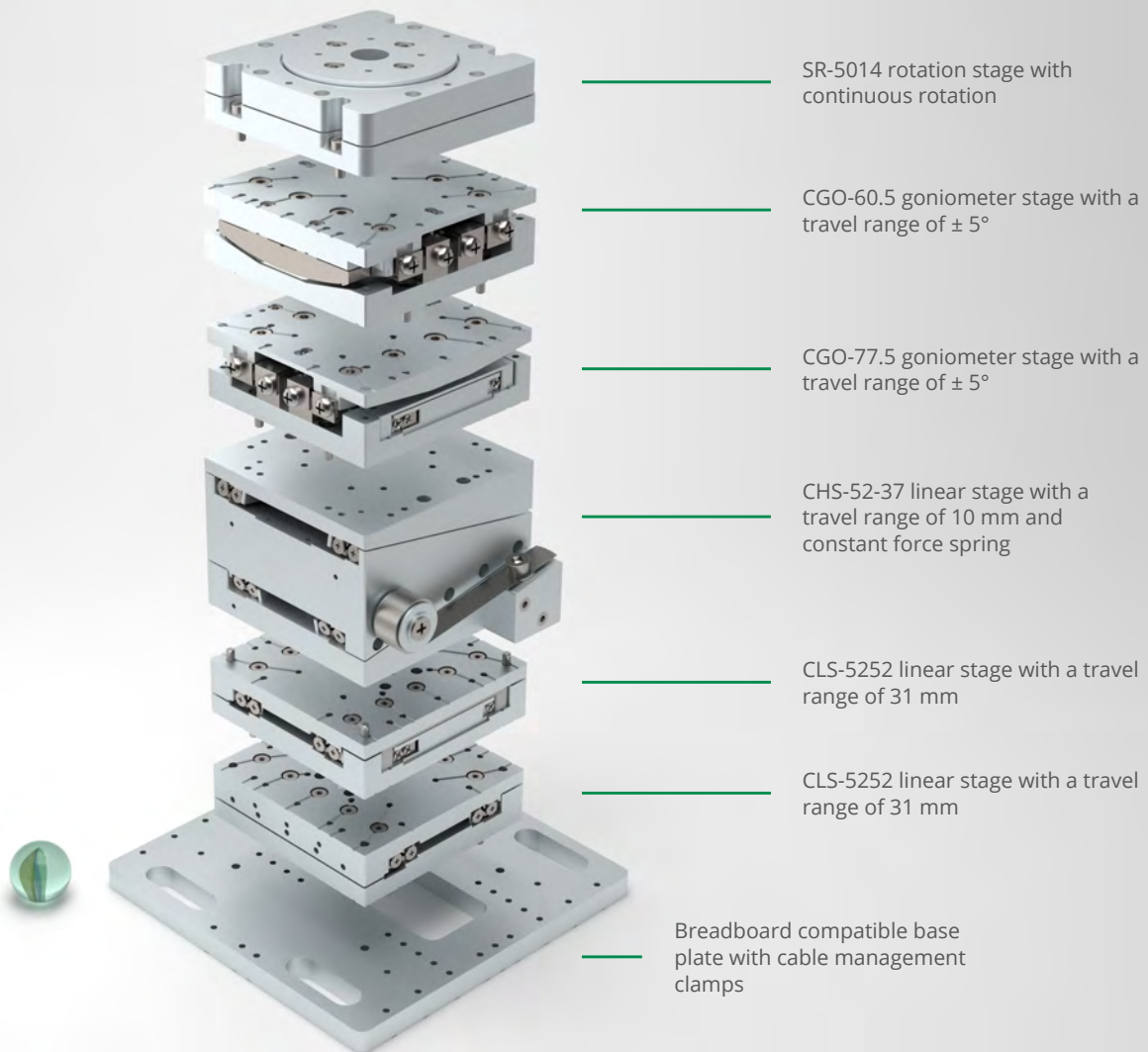
Cable Management

The SmarAct modular system also includes clamps for cable management. Various clamp sizes are available, optimized to securely hold a defined number of cables with different diameters

Due to the high modularity and large number of components and accessories, the **SMARBOTIC** modular system offers almost endless possibilities to build your very own setup with one or more degrees of freedom.

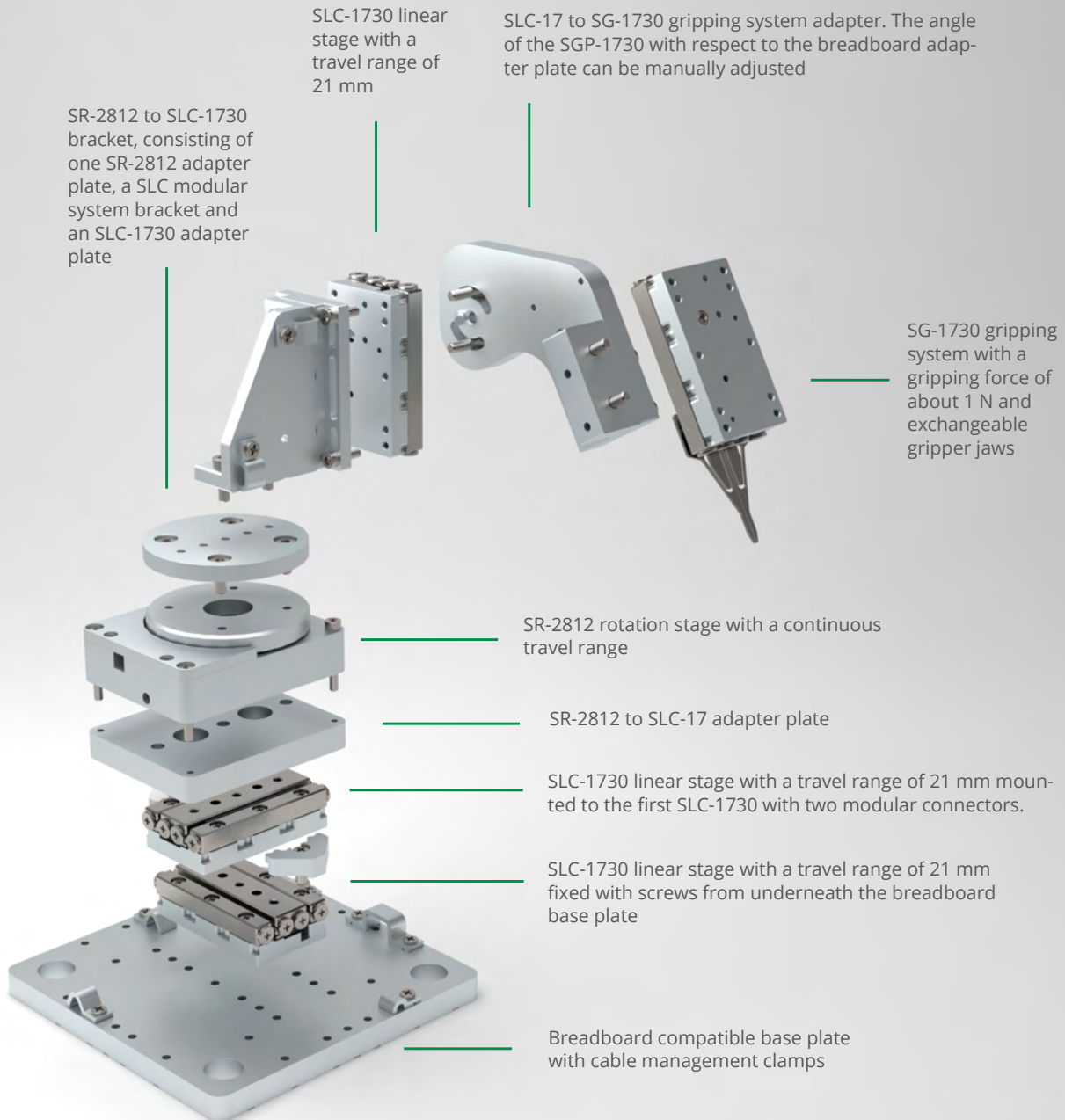
SMARBOTIC® - Modular System

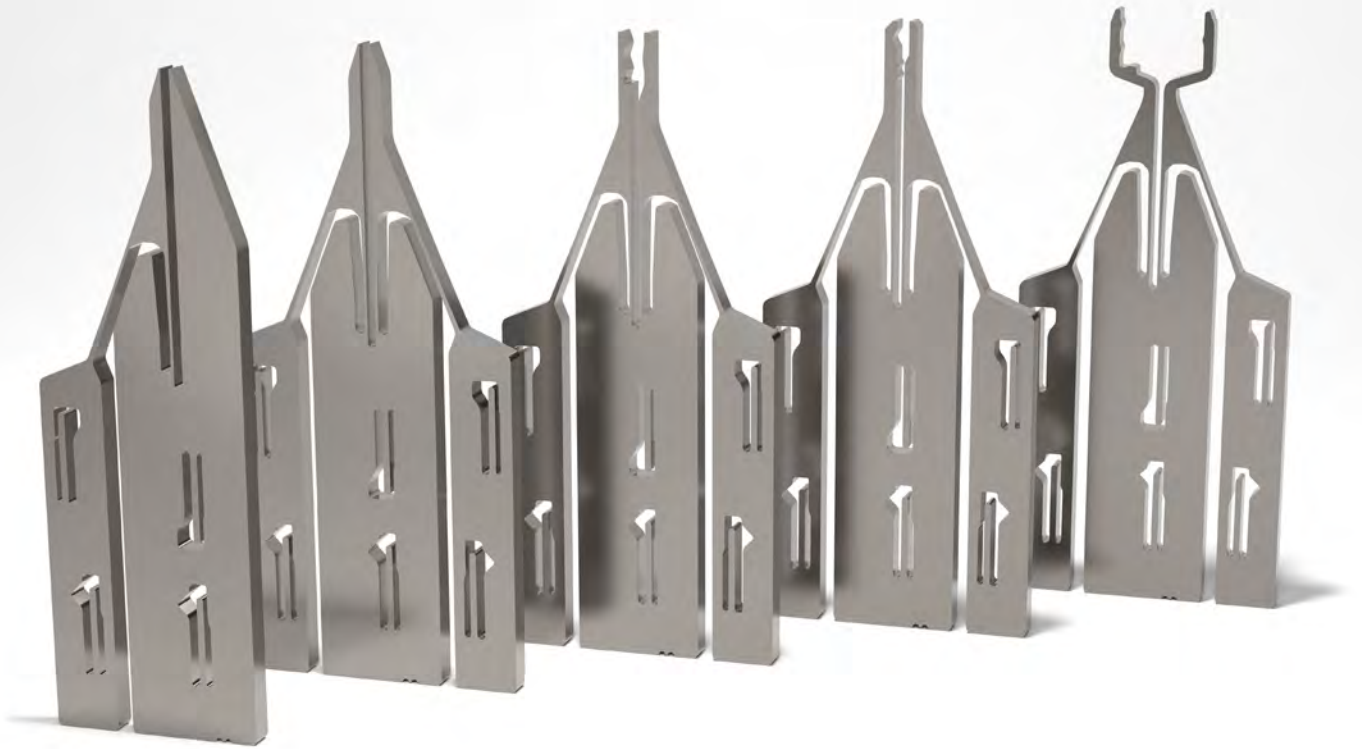
1st Example: 6D Positioning System



SMARBOTIC® - Modular System

2nd Example: 5D Micromanipulation Device





SMARBOTIC® MICRO-GRIPPERS

Micro-Grippers: Precise Gripping and Handling of Fragile Objects

Precise handling of parts and tools at automated assembly lines and sample handling and manipulation in life science are often most crucial tasks. We have complemented our product portfolio with versatile gripping solutions to address the growing demand. **SMARBOTIC** micro-grippers consist of linear **SMARSLIDE**® stages and gripping

jaws that can be easily exchanged and customized if required. When equipped with a position sensor, the microgrippers allow full control over the gripping process. In addition, force sensors integrated into the parallel microgripper SGP-17F allow to control not only the jaw opening but also the gripping force when handling fragile objects.

Key Features:

Manipulating small fragile objects with high-precision

Every gripper remains in position, even without power supply

Based on SmarAct stages, the grippers allow for an opening of up to several millimeters while maintaining very precise gap width control

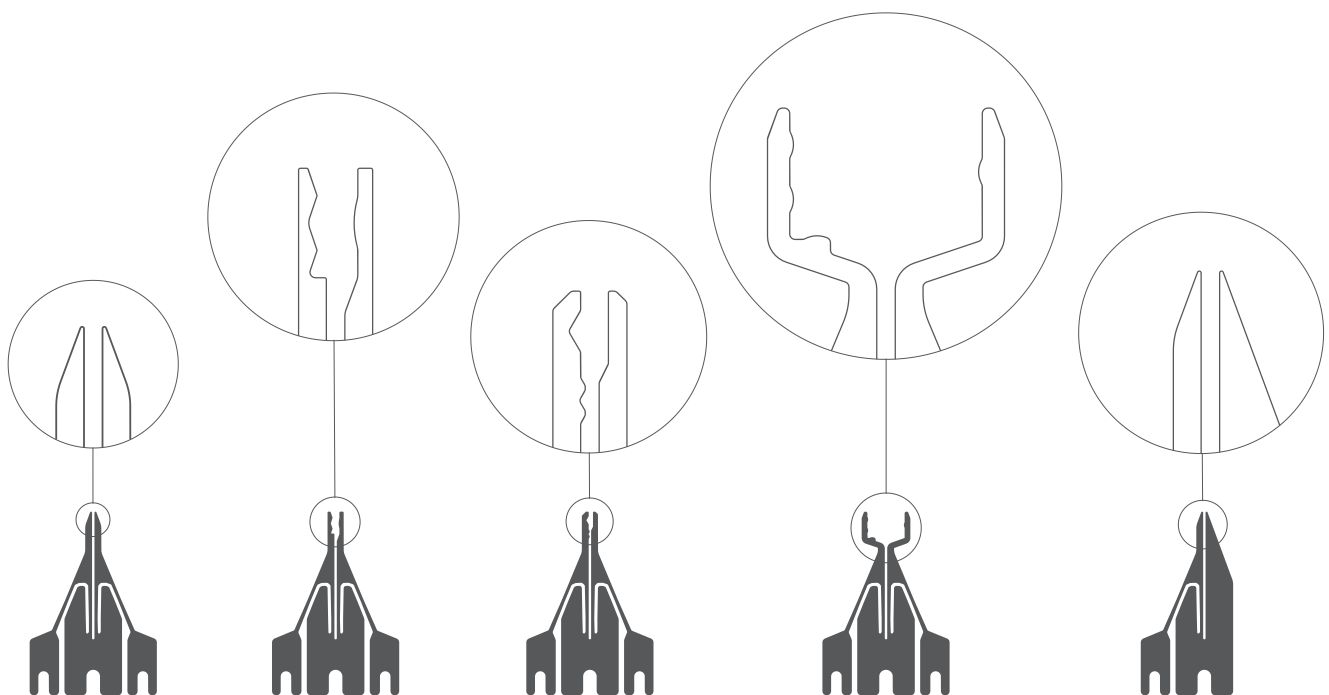
Gripper jaws are exchangeable or permanently attached to the positioner depending on your application

Due to the exchangeable jaws, you can always work with the jaw shape most suitable for your application

All grippers and jaws can be individually designed to fit your needs

Over the years, various jaw shapes have been developed that are tailored for different object geometries and sizes. Examples include jaws for cylindrical, spherical and rectangular objects as well as dedicated designs to handle delicate optical components such as lenses and fibers. The gripper jaws are made of conductive material

such as stainless steel and available in different material thicknesses. All designs can be adapted and fully customized to meet your exact specific requirements. Please feel invited to contact our application specialists to design the jaw shape that perfectly matches the objects you would like to manipulate.





SGE-17 with exchangeable gripper jaws.

Gripper SGE-17

- Screwed gripper jaws can be easily exchanged on site
- Very compact and versatile tool for handling of optical and electronic components
- Optional integration of position sensors to control and monitor the gripping process
- Available in a (ultra)-high vacuum version



SGQ-17 with magnetic quick-exchange.

Gripper SGQ-17

- Quick-exchange system for a tool-free exchange of gripper jaws
- Very compact and versatile tool for handling of optical and electronic components
- Optional integration of position sensors to control and monitor gripping process
- Available in a (ultra)-high vacuum version



SGP-17F with integrated force sensors.

Gripper SGP-17F

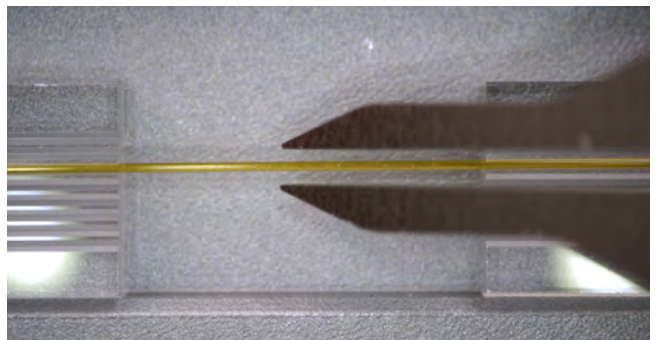
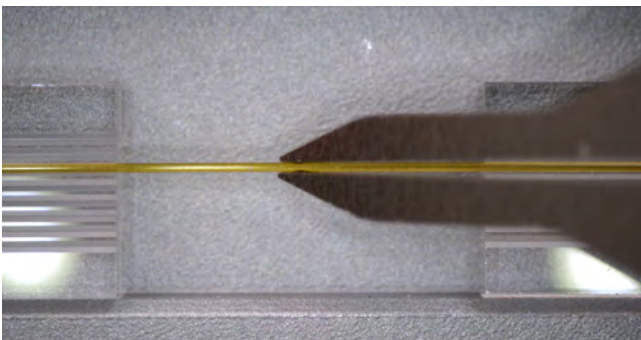
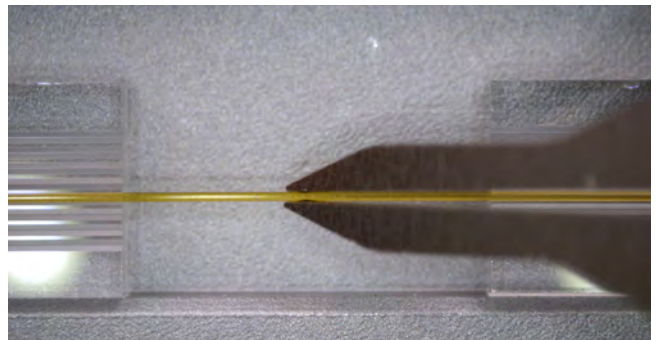
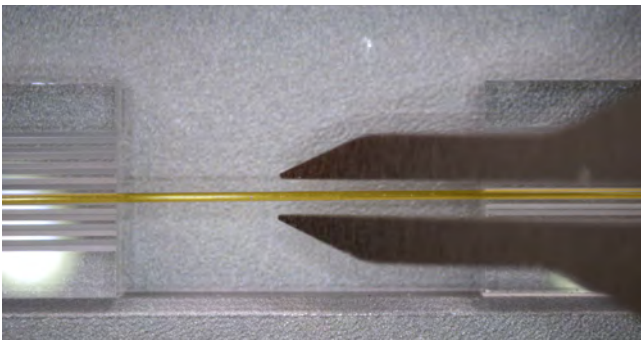
- Perfectly suited for handling lightweight and fragile objects thanks to the sensitive force and position sensors
- Equipped with one biaxial load cell per jaw, allowing for individual measurement of parallel gripping force and orthogonal contact force
- Parallel gripping over the whole gripping range

		SGE-17	SGQ-17	SGP-17F
Mechanical	Opening [mm]	< 1		< 20.5
	Gripping Force [N]	1		3.5
	Dimension [mm], L x W x H	17 x 25.5 x 9	17 x 32 x 13.4	30 x 35 x 14
	Weight [g]	14	28	40
	Jaw Types	Exchange	Quick-Exchange	Solid
Open-Loop	Gripping Time [ms]	< 10		
	Gripping Resolution [nm]	< 10		1
Closed-Loop	Sensor Types	S, L		
Material Options		Aluminum as standard; Black anodized (-BK)		
Vacuum Options		HV (10 ⁻⁶ mbar); UHV (10 ⁻¹¹ mbar)		

Application Example: Pick-and-Place Handling of Optical Fibers



By combining our 3D modular system with our SGE-17 microgripper powerful handling stations are created that can be used for different manipulation tasks of micro- and nanoscale objects. In this example, the pick-and-place handling of individual optical fibers with a diameter of $150\ \mu\text{m}$ is demonstrated. The integrated sensors and high accuracy of our positioning systems enable fast and easy automation of complex pick-and-place sequences.



Control Systems: From Point-to-Point Movements to Real Motion Control

SMARBOTIC® motion systems like our **SMARPOD®** and **TRIPOD** usually have multiple axes. SmarAct **MCS2** controllers are used to drive and control the individual axes. However, an **MCS2** controller does not inherently understand the mechanical structure of a multi-axis motion system or how each axis contributes to the overall position. The precise movement of a motion system along a path in space requires the coordinated movement of all its axes.

To control the motion system in Cartesian coordinates (the pose space), e.g., to move the mechanical interface or an end effector mounted on the interface to a position and orientation in space, a coordinate transformation must be calculated that translates the target pose into positions for each axis.

This is precisely the role of the ECM controller. Previous ECM versions were able to control the accuracy of the target pose of a motion (point-to-point movement), but not the accuracy of the movement path. The new ECM 3 motion controller together with **MCS2** axis controllers with EtherCAT®

interface now also offers a high path accuracy to be achieved when moving to a target position. Motion paths are interpolated by the ECM 3 controller and deviations from the path are corrected continuously.

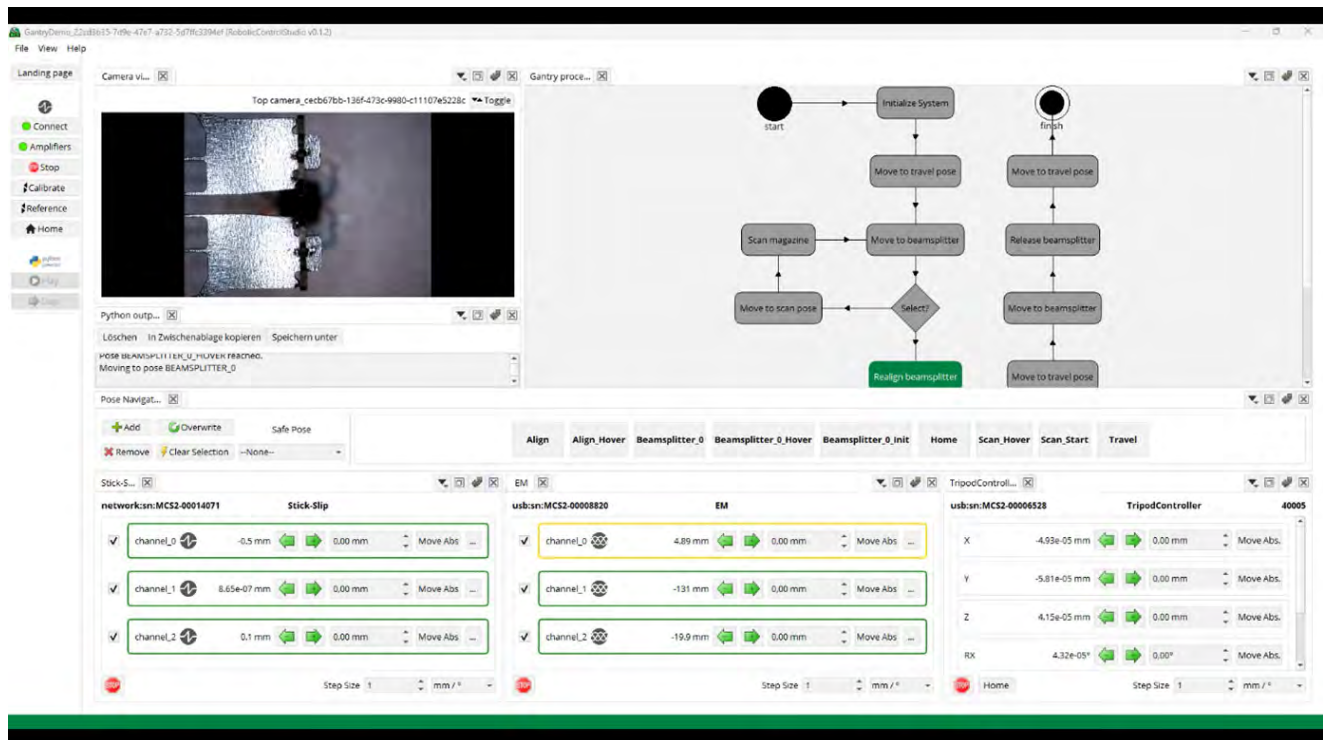
Several SmarAct motion systems can be controlled simultaneously by one ECM 3.

The new ECM 3 has two additional network ports that can be used for communicating with **MCS2** controllers. Both additional network ports can either be configured for EtherCAT® or TCP/IP communication, supporting **MCS2** controllers with EtherCAT® and Ethernet interfaces. Furthermore, **MCS2** controllers with USB interface are supported as well.

In addition, the new ECM 3 has 8 programmable digital I/O pins. Configured as an input, a pin can be used to trigger activities when the input signal changes. An output pin can be programmed to indicate motion events, for instance, starting or stopping of a movement.



Software: New Control Software for Robotic Applications



The upcoming control software for robotic applications creates a new platform with a modular and expandable structure. Easy and fast control of all SmarAct positioners and systems via UI and API with optional graphical process design allows the development of low-code applications for quick and efficient solutions.

Process development is enabled by using the popular Python scripting language. Integration in signal- or message-driven process chains is possible by supporting widely-used communication standards.

The platform provides access to a growing library of ready-to-use applications and supported hardware like controllers, cameras, sensors and more. Also, a set of configurable widgets for visualizing the process flow, controlling devices, displaying video streams and live plotting data functionality are available. Pre-built algorithms and pre-defined building blocks facilitate process design and development.

Functional components, known as plug-ins, enable the software system to be expanded by customers,

for example, to integrate special hardware or algorithms achieving platform-wide synergy effects. In addition, Python with its modules can be fully utilized for individual use cases.

With this toolbox, it is possible to accelerate and simplify the development of customized processes for various application areas, such as industrial stand-alone and process chain applications, rapid prototyping or scientific research. The modular architecture allows the shifting of development effort between the customer and SmarAct, offering great flexibility. A customer release is planned for the end of 2025.

With the development and production of market-leading solutions in the field of high-precision positioning, automation and metrology, the SmarAct Group reliably accompanies their customers in achieving their goals. The broad product portfolio – from single positioning stages to complex parallel kinematics, miniaturized robots, control systems and measurement technology – is complemented by automated microassembly solutions. Even the most challenging customer requirements can be met by maximum adaptability and complete in-house production.

Since its founding in 2005, SmarAct has steadily grown from a small team of engineers to a group of companies with three independent business units and over 270 highly skilled members. Today, SmarAct relies on years of experience and, above all, on a very passionate team with unconditional customer focus.

Headquarters

SmarAct GmbH

Schuetze-Lanz-Strasse 9
26135 Oldenburg
Germany
T: +49 441 – 800 87 90
T: +49 441 – 559 79 18 0
Email: info-de@smaract.com
www.smaract.com

USA

SmarAct Inc.

2140 Shattuck Ave. Suite 302
Berkeley, CA 94704
United States of America
T: +1 415 – 766 90 06
Email: info-us@smaract.com
www.smaract.com