

White paper

HUMANOID ROBOT REPORT 2027

igus® future

igus®

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Introduction

Humanoid robots are no longer just a vision. But what does this mean for your industry, your competitiveness and, above all, for your future? This white paper provides you with up-to-date answers to developments that are becoming reality faster than many expect.

This is because our real-world experience shows how consistently new technologies are being industrialised today. For example, the lettuce harvesting robot developed by AI.Land GmbH uses cobot arms from our modular system and was awarded the title of the DLG Agrifuture Concept Winner.

The path from the development laboratory to the application is shorter today than ever before. Our goal is to make humanoid robotics economically scalable and affordable for OEMs.



Source: igus®

Dexterity: Game changer in humanoid robotics



Source: igus®

With every wave of innovation in the development of humanoid robots, one aspect becomes increasingly important: Dexterity in the manipulation of objects. While earlier development phases focused on mobility and interaction, today the ability to manipulate a wide variety of objects safely, flexibly and with fine motor skills is one of the most important growth drivers. Hand and finger mechanisms with several degrees of freedom, tactile sensors and intelligent control systems enable modern robots to perform complex sorting and assembly tasks, grip sensitive components and co-operate with humans.

The technological leap in this area is based on three pillars:

- Advances in sensor and actuator technology that enable precise force control and adaptive gripping.
- Artificial intelligence to be able to react dynamically to new objects and situations.
- New lightweight materials and modular components that enable the integration of highly complex finger mechanisms at reduced costs.

Market forecasts show: Manufacturers and industry are increasingly focusing on advanced gripping systems and AI-based motion planning in order to integrate finger-ready robots into production, logistics, the service sector and even households. Multimodal sensor technology, adaptive software, flexible mechanics and adaptive finger systems allow robots to grasp and dynamically manipulate variable objects. These are tasks that were previously considered too complex for automation.

This new level of precision manipulation opens up an unprecedented range of applications, particularly in the industrial environment and in the service and care sectors: From the assembly of tiny electronic parts to assisted dressing or help in the household. It is already clear today that the markets are not only demanding autonomy, but increasingly also flexibility of use and dexterity.

Humanoid robots: On the way to becoming a key strategic technology

Advances in artificial intelligence, sensor and actuator technology are enabling humanoid robots to take on tasks that were previously considered impossible to automate. They interact with customers in retail, support carers in healthcare and perform monotonous or dangerous tasks in industry. At the same time, society's need for flexible, adaptive solutions is growing - not least due to demographic change and the increasing shortage of skilled labour in many countries.

But the development of humanoid robots is more than just a technical challenge. It raises key questions: How do machines, which are becoming more and more similar to us in appearance and behaviour, change our understanding of work, interaction and responsibility? What are the opportunities for companies that are early adopters of this technology – and what risks need to be addressed?

This igus® report analyses how science fiction is turning into a billion-dollar market, which technological and economic drivers are determining its development and why the time has never been better for your entry into humanoid robotics.

Technological breakthroughs as drivers

The decisive impetus for today's generation of humanoid robots came from several directions.

- **Sensor and actuator technology:** Advances in miniaturised sensors and powerful, lightweight actuators now enable movement sequences that come very close to the human model. Intelligent force and position sensors allow adaptive reactions to the environment – a decisive step towards safe interaction with people
- **Artificial intelligence:** The integration of AI and machine learning is taking humanoid robots to a new level. Systems such as Tesla Optimus or Figure 01 benefit from algorithms that enable motion planning, object recognition and even social interaction in real time
- **Material technology:** New materials – especially lightweight, wear-resistant plastics – have accelerated the development of robots that are not only efficient, but also durable and low-maintenance

Learning curves and paradigm shifts

Past experience shows that the greatest leaps in innovation are achieved where interdisciplinary teams from mechanical engineering, computer science and materials science work together.

Successful projects such as Honda ASIMO or Boston Dynamics Atlas show that iterative development, intensive test cycles and early integration of user feedback are crucial. At the same time, the standardisation of interfaces and components – for example through open software platforms or modular hardware – has significantly improved the scalability and marketability of humanoid robots.

What is staying the same? What is changing?

Many of the challenges of the past – such as balance, energy efficiency and intuitive controls – can now be addressed by technological advances. Nevertheless, the complexity remains high: The coordination of hundreds of sensors and actuators, safe human-robot interaction and adaptation to unstructured environments continue to demand innovative solutions.

The key question is therefore:

How can the experience gained from decades of research and development be translated into scalable, economically viable products? The answer lies in the consistent use of new technologies, the focus on modular designs and the close integration of hardware and software.

13 billion US dollars by 2028 – why humanoid robots are taking off now

The market for humanoid robots is in a phase of dynamic growth. According to recent analyses by MarketsandMarkets, the global market volume for humanoid robots is expected to grow from around USD 1.8 billion in 2022 to over USD 13 billion in 2028. This corresponds to an average annual growth rate of over 40%.

Particularly noteworthy is the high willingness to invest in Asia, where countries such as Japan, China and South Korea act as innovation centres and are investing considerable resources in research, development and commercialisation. Market momentum is also high in North America and Europe, driven by the need for automation, demographic change and the increasing acceptance of robotics in everyday life. While North America is primarily characterised by technological leadership and a strong ecosystem of start-ups and established companies, European markets benefit from targeted funding programmes and close links between research and industry.

Dynamics in the robotics market: Three forces driving humanoid robotics

Demographic change

The ageing population in industrialised countries is increasing the need for assistance robotics, particularly in the care and healthcare sector. Humanoid robots are seen as a key technology for alleviating the shortage of skilled labour and improving the quality of life of older people.

Technological progress

Innovations in AI, sensors, actuators and materials science have significantly increased the performance of humanoid robots. Advances in battery technologies and energy efficiency enable longer operating times and more complex task profiles. At the same time, new software architectures ensure better integration into existing IT and production environments.

Cost reduction and economies of scale

As market penetration increases, production costs fall, particularly through the use of standardised components and manufacturing processes. This makes humanoid robots affordable for new user groups and markets.

Challenges on the way to widespread use

High investment and development costs

The development of humanoid robots requires considerable financial resources and many years of research. This represents a barrier to entry for smaller companies and start-ups in particular.

Safety and acceptance issues

Safe interaction with people and social acceptance are key challenges. Concerns about data protection, ethical aspects and possible job losses must be addressed to enable a broad market launch.

Regulatory uncertainties

Different regulatory frameworks in the target markets make scaling and international rollout more difficult. In addition, there is often a lack of binding standards for safety-critical applications.

Will the main players remain the leaders or will the markets now be redistributed?

The market is characterised by a mix of global technology groups, specialised robotics companies and innovative start-ups. The leading players include:

- **Boston Dynamics:** Pioneer in the development of highly mobile, dynamic robots. Known for models such as Spot and Atlas, which are used in industry, safety and research in particular
- **Unitree Robotics:** Leading supplier of affordable quadrupedal and humanoid robots for research, education and industry. Recognised as one of the world's largest manufacturers of quadrupedal robots
- **SoftBank Robotics:** Known for the humanoid robot Pepper, which is used worldwide in the service sector and for customer interaction
- **Honda:** One of the pioneers of humanoid robotics together with ASIMO
- **Toyota:** Focusing on assistance robotics and mobility solutions
- **Tesla:** On the way to scaling humanoid robots for industrial applications with the Optimus project
- **Figure AI:** Develops robust, versatile humanoid robots for logistics and production
- **UBTECH Robotics:** Leader in education and entertainment with humanoid robots like Walker
- **Agility Robotics:** Specialised in bipedal robots for logistics and delivery
- **Hanson Robotics:** Known for Sophia, a humanoid robot with advanced facial expressions and AI-based interaction

"The speed with which humanoid robots are making the leap from research to real-life applications is unprecedented. We are currently witnessing the emergence of a billion-euro market that is redefining not only automation, but also the interaction between man and machine. Open platforms, modular architectures and the ability to quickly translate innovations into scalable products will be decisive for success."

Modar Alaoui
Founder and General Partner at
ALM Ventures

The coming years will be characterised by an increasing diversification of applications. In addition to traditional fields of application such as industry and service, new areas such as education, research, entertainment and even private households are gaining in importance. The ability to flexibly adapt humanoid robots to different tasks is becoming a decisive competitive factor. The humanoid robotics market is facing a phase of exponential growth. Companies that focus on modular, scalable and cost-efficient solutions at an early stage will secure a decisive lead in a market that has the potential to fundamentally change the world of work and social life.

Which types of humanoid robots have a future

Today, the variety of humanoid robots is greater than ever. While early developments were aimed at technically reproducing a human in its entirety, the market is increasingly differentiated according to application, degree of complexity and technical design. For decision-makers and developers, it is crucial to understand which types of humanoid robots exist, how they are classified and which fields of application result from this. This differentiation forms the basis for product development, investment decisions and strategic partnerships.



Fully humanoid robots

Fully humanoid robots are systems that replicate the human body as completely as possible in terms of form and function. They have a head, torso, two arms and two legs and are designed to recreate complex movement sequences and interactions. The aim is to take over tasks that were traditionally reserved for humans – for example in industry, in the service sector or in direct contact with customers and patients. Examples of fully humanoid robots are:

- **Unitree H1:** An electrically powered humanoid robot focusing on running stability, speed and balance. Developed for research, industrial applications and AI-supported interaction
- **Tesla Optimus:** Developed for industrial applications, with a focus on mobility, payload and interaction in human environments
- **Figure 01:** A versatile robot characterised by high mobility and adaptability
- **Honda ASIMO:** Pioneer of bipedal robotics, known for its ability to walk, run and communicate with humans

Fully humanoid robots are the most technically sophisticated category. They require highly developed kinematics, advanced sensor technology and powerful actuators to enable balance, coordination and interaction on a human scale. The development costs and technical outlay are correspondingly high, but the range of applications is broad: From industrial automation and research to assistance and service tasks.



Source: igus®

Special types of humanoid robots

However, the diversity of humanoid robotics goes far beyond classic, human-like shapes. Specialised robot types specifically address niche applications, research needs or special requirements in terms of size, modularity and controls. These types offer decisive advantages, particularly in education, research, hazardous environments or for flexible system architectures.

Miniature humanoids

Miniature humanoids are compact, often cost-effective robots that have been specially developed for educational purposes, robotics workshops and research laboratories. Their lightweight, moderate complexity and ease of programming make them ideal platforms for getting started in robotics and artificial intelligence. They are used in schools, colleges and universities to teach the basics of robotics, sensor technology and programming or to test new algorithms.

- Robotics and AI education in schools and universities
- Research into human-robot interaction on a small scale
- Participation in international robotics competitions
- Prototyping and development of new control algorithms

Avatar robots

Avatar robots are controlled remotely by humans and make it possible to perform tasks in dangerous, inaccessible or remote environments. They transmit movements, speech and often also haptic feedback in real time so that the operator can act from a distance as if they were "on site".

- Use in disaster areas, for example for search and rescue
- Remote operations in hazardous industrial plants or research facilities
- Telepresence in care, medicine or education (e.g. for people with reduced mobility)
- Participation in international competitions for the development of avatar technologies

Modular robots

Modular humanoid robots are designed in such a way that individual body parts – such as arms, legs or sensor modules – can be flexibly exchanged, extended or reconfigured. This architecture enables a high degree of adaptability to changing requirements and different tasks. It is particularly suitable for research, development and applications where versatility and rapid retooling are required.

- Research laboratories for developing and testing new components
- Industrial environments with changing automation tasks
- Education and training with a combination of different robotics modules
- Prototyping and rapid adaptation to new fields of application

Semi-humanoid robots: Body segments for specialised tasks

Not every application requires a complete humanoid robot. Instead of reproducing the entire human body, these systems focus specifically on individual segments – such as the upper body, arms, hands, legs or head. This significantly reduces complexity and costs, while the functionality is tailored precisely to the respective application.

Upper body with arms and head, without legs

These robots are designed for interaction and communication. They usually have a head equipped with sensor technology (e.g. cameras, microphones) and at least one movable arm. By dispensing with a complex drive system, they concentrate on tasks such as greeting, providing information or performing simple handling tasks.

- Reception and information systems in hotels, public authorities or airports, where they welcome visitors, provide information or perform simple service tasks
- Customer service and advice in retail, for example as interactive info points or for product presentations
- Educational institutions where they are used as teaching and demonstration systems for robotics and AI
- Medical assistance, for example for patient registration or telepresence in clinics

They require highly developed kinematics, advanced sensor technology and powerful actuators to enable balance, coordination and interaction on a human scale. The development costs and technical outlay are correspondingly high, but the range of applications is broad: From industrial automation and research to assistance and service tasks.

Arms/manipulators

Robot arms are the backbone of modern automation. They perform precise assembly, testing or handling tasks and are used in industry as well as in laboratories and research. Many of these systems are designed as cobots (collaborative robots): They work safely and directly with humans, have integrated sensors for force feedback and enable flexible integration into existing work environments. One specific example is the igus® ReBeL. This modular robot arm can be flexibly integrated into various applications – from the automation of small production steps through to research. Designed as a cobot, it is particularly suitable for direct collaboration with humans as it has integrated safety functions and an intuitive operating concept.

- Automation of production steps, e.g. pick-and-place, screwing or testing tasks in the electronics and automotive industry
- Laboratory automation, for example for processing samples or pipetting in medical technology
- Picking and packing in logistics, where flexibility and precision are required
- Research and development, e.g. for material tests or prototyping

Hands/fingers

Replicating human hands and fingers is one of the biggest challenges in robotics. Semi-humanoid gripping systems have several degrees of freedom, tactile sensors and sensitive drives. They enable the gripping, sorting and manipulation of objects of different shapes, sizes and composition

- Sorting and gripping tasks in logistics, such as handling a wide variety of packaging
- Assembly and handling of small, sensitive components in the electronics or watchmaking industry
- Assistance systems in care and rehabilitation where fine motor precision and gentle movements are required
- Laboratory automation for precise pipetting or dosing tasks



Source: igus®

Legs/exoskeleton

Robots that only replicate legs or leg modules are mainly used in gait research, rehabilitation and industry. Exoskeletons support or replace human movement functions, for example when walking, standing or lifting heavy loads. They open up new potential in medical therapy, care, logistics and civil protection. Bipedal leg modules also enable navigation on uneven terrain and obstacles to be overcome.

- Medical rehabilitation, e.g. for gait training after a stroke or paraplegia
- Support for carers when lifting heavy loads
- Logistics and material handling for transporting heavy goods in warehouses
- Civil protection and rescue operations in difficult terrain



Source: igus®

Heads

Robot heads specialise in social interaction and communication. They have sensors for facial recognition, speech processing and facial expressions to enable dialogues that are as natural as possible. Areas of application include education, research, customer service and human-machine interaction in public spaces. The ability to recognise and express emotions is increasingly seen as the key to the acceptance of humanoid systems.

- Education and research on human-machine interaction
- Customer service and reception areas - digital assistance or information terminals
- Therapy and assistance systems for people with special needs, e.g. in speech therapy
- Public spaces for communicating information or as brand ambassadors in marketing



Source: igus®

Progress in motion: How humanoid robots walk, roll and adapt

The type of movement is a key distinguishing feature of humanoid robots and largely determines their possible applications, technical complexity and adaptability to different environments. While human locomotion serves as a model, three basic movement principles have become established in robotics: Bipedal movement, wheel-driven systems and hybrid approaches. Each of these variants has specific advantages and disadvantages and addresses different requirements from practice and research.

Bipedal movement

Bipedal robots move on two legs, imitating the human gait. This principle enables them to overcome obstacles, climb stairs and move around in environments designed for people – such as offices, homes or production halls. However, bipedal locomotion is technically extremely demanding: It requires precise controls of balance and coordination, a large number of sensors for position recognition and highly developed algorithms for movement planning. In addition, the energy requirement is significantly higher compared to other types of movement, as the constant balancing and complex kinematics require a lot of computing and drive power.

Benefits:

Overcoming obstacles, utilising existing human infrastructure, high adaptability

Disadvantages:

Complex balance and control, high energy consumption, costly maintenance

Wheel-driven movement

Wheel-driven humanoid robots rely on wheels as a locomotion mechanism. This solution is significantly more energy-efficient, more stable and faster than the bipedal version. The technical effort required for the balance and control system is lower, which simplifies development and maintenance. However, wheel-driven systems are dependent on level and firm surfaces and can only overcome obstacles such as steps or uneven terrain with difficulty. They appear less human-like, but are particularly suitable for many industrial and service-orientated applications – for example in retail or warehouses.

Benefits:

Efficient, fast, stable, lower energy consumption

Disadvantages:

Limited mobility on uneven terrain, less human-like appearance



Wheel-driven movement,
Source: igus®

Hybrid systems

Hybrid humanoid robots combine bipedal and wheel-driven locomotion. For example, they have fold-out wheels in the feet that can be activated as required. This allows longer distances to be travelled efficiently and quickly on wheels, while switching to bipedal mode for complex environments or obstacles. This flexibility enables a wide range of applications – from logistics and production to service and rescue robotics.

Benefits:

Maximum flexibility, efficient movement over long distances, possible to overcome obstacles

Disadvantages:

Increased technical complexity, potentially higher maintenance costs

New worlds of work: Where humanoid robots create real added value

The fields of application for humanoid robots are developing rapidly and now extend far beyond traditional industrial and service tasks. Advances in artificial intelligence, sensor technology and material technology are constantly opening up new markets and application scenarios.

Assistance robotics and care

Humanoid robots take on supportive tasks in nursing, healthcare and caring for the elderly. They help with mobilisation, remind people to take medication, assist with personal hygiene or provide company. Thanks to their human-like appearance and ability to communicate, they can reduce inhibitions and increase user acceptance.

Industrial automation

In manufacturing and assembly, humanoid robots take on complex, repetitive or ergonomically unfavourable tasks. They are able to react flexibly to changing production requirements, grip and assemble workpieces and carry out quality checks. Their advantage lies in their adaptability to existing workplaces designed for people.

Education and research

Humanoid robots are established as teaching and demonstration platforms in schools, colleges and universities. They teach the basics of robotics, AI and programming, promote interdisciplinary learning and serve as a testing ground for new algorithms and interaction concepts.

Entertainment and marketing

In the entertainment sector, humanoid robots appear as presenters, actors or brand ambassadors. In the retail and hotel sectors, they are responsible for reception, customer advice and product presentations. Their ability to interact and make facial expressions increases attention and enhances the customer experience.

Search and rescue

In disaster and hazardous situations, humanoid robots can be used to explore areas that are dangerous or difficult to access, locate people and initiate first measures. Their human-like mobility allows access to buildings or ruins that are impassable for conventional machines.

Logistics and material handling

Humanoid robots take on tasks such as picking, sorting or transporting goods in warehouses and logistics centres. Thanks to their flexibility and adaptability, they can operate in dynamic, human-centred environments and cooperate with other systems.

Research and space exploration

In space travel and scientific expeditions, humanoid robots are used to perform dangerous or monotonous tasks, collect samples or carry out maintenance work. Their human-like kinematics enable them to be used in environments that would be difficult or life-threatening for humans.

Inspection, maintenance and cleaning

Humanoid robots are increasingly being used for inspection, maintenance and cleaning tasks in inaccessible or hazardous environments – for example in energy supply, offshore facilities, tunnels or high-rise buildings. They can check facilities, carry out repairs or perform cleaning work without endangering people.

Security and monitoring

In security-critical areas – such as airports, railway stations or at major events – humanoid robots take on tasks in surveillance, access control and hazard prevention. They can address people, react to suspicious activities and transmit relevant data to security centres in real time.

Household and personal assistance

As technology matures, humanoid robots are also being used as personal assistants in the private sphere. They help with everyday tasks such as cleaning, cooking, shopping or looking after children and pets. Their potential lies in relieving people of routine tasks and improving their quality of life.

Technology is not the only thing that counts: Economic efficiency, sustainability, regulation

Economic efficiency, sustainability and regulation are the three key levers for the long-term success of humanoid robotics. Those who opt for resource-saving materials, energy-efficient designs and maintenance-free components can not only keep costs down, but also overcome regulatory hurdles more easily and secure social acceptance. The integration of predictive maintenance, digital tools and modular construction methods makes humanoid robots economically attractive and future-proof – for large companies and SMEs alike.

Economic aspects: TCO, ROI, scalability

Total cost of ownership (TCO)

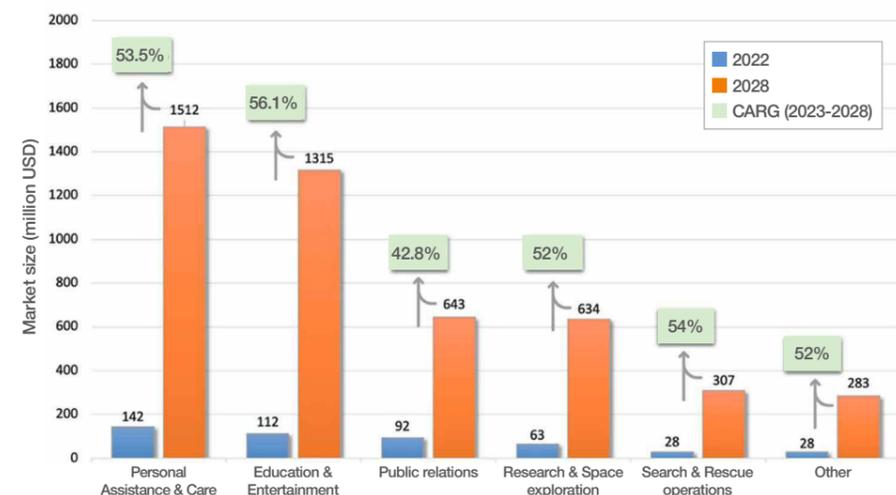
The cost-effectiveness of humanoid robots is not only measured by the acquisition costs, but above all by the total costs over the life cycle. Maintenance-free components, such as those offered by igus® with lubricated bearings and gearboxes, reduce running costs considerably. The elimination of lubricants, less wear and reduced downtimes lead to predictable, low operating costs.

Return on investment (ROI)

A fast ROI is crucial for investors and users. The scalability of modular robotic systems makes it possible to start with pilot applications and, if successful, quickly expand to larger quantities or new fields of application. By integrating standardised, cost-effective components and digital tools for calculating service life, investments can be calculated precisely and risks minimised.

Scalability and flexibility

The modular design of humanoid robots makes it easier to adapt to new tasks and markets. Standardised interfaces and assemblies enable efficient series production, while individual adaptations can be implemented economically through additive manufacturing or flexible bar stock products. This makes humanoid robotics accessible to SMEs and new fields of application.



"The greatest opportunities for humanoid robots lie in their versatility: They can take on tasks that were previously considered too complex or too human. Whether in the care, logistics or education sector – humanoid systems are increasingly becoming the link between technology and everyday life. It is crucial that we now set the right standards for safety, ethics and interoperability."

Jesica Chavez
Robotics Expert and
Startup Advisor

Choice of materials and circular economy

The development of sustainable humanoid robots starts with the choice of materials. Modern systems increasingly rely on lightweight, wear-resistant plastics and recyclable materials in order to minimise the ecological footprint. The use of self-lubricating polymer components – such as those offered by igus® – eliminates the need for external lubricants, reduces maintenance costs and prevents the release of potentially harmful substances into the environment.

Energy efficiency and operation

Energy efficiency is a key criterion for the sustainability of humanoid robots. Advanced drive technologies, intelligent motion planning and adaptive control systems significantly reduce power consumption. Lightweight construction and optimised kinematics reduce the drive power required, which not only cuts operating costs but also CO₂ emissions. Compared to conventional metal components, innovative polymers offer a significant reduction in weight and therefore lower energy requirements during ongoing operations. Predictive maintenance and digital twins help to minimise downtimes and make optimum use of resources.

Sustainability as a competitive factor

Sustainable robotics are increasing in demand by customers, investors and regulators. Companies that focus on resource-saving materials, energy-efficient designs and recyclable components gain a clear market advantage and fulfil growing ESG requirements.

Regulatory requirements and ethical issues

Regulation: Safety and standards

With the increasing use of humanoid robots, safety and compliance requirements are rising. International standards such as ISO 13482 (safety of personal assistance robots) or the EU Machinery Directive define minimum standards for design, operation and interaction with humans. Manufacturers must carry out extensive risk analyses, tests and certifications to ensure market access and liability security.

Data protection and AI governance

Humanoid robots that work with sensitive data or make decisions autonomously are subject to strict data protection and IT security requirements. The EU AI Act and comparable regulations worldwide set clear framework conditions for the use of AI in safety-critical applications. Transparency, traceability and the possibility of human intervention are key requirements.

Ethical challenges

In addition to technology, ethical questions are also arising: How can discrimination be avoided through algorithms? How is user privacy protected? And how are responsibilities distributed between man and machine? Companies are required to establish ethical guidelines, involve stakeholders and actively promote social acceptance.

What do you need to build the next generation of robots?

Humanoid robots are highly complex mechatronic systems that consist of a large number of specialised hardware and software components. The integration of these components determines the mobility, interaction capability, energy efficiency and reliability of the systems. A modern humanoid robot combines highly developed sensor technology, powerful actuators, modular control systems, energy-efficient power supply and advanced software. Only the seamless interaction of these components enables human-like movements, safe interaction and economical operation – and is therefore the basis for the next generation of humanoid robotics.

The overview provides an up-to-date, structured summary of the most important technologies and components used today in modern humanoid robots.

Hardware components

Components	Function
Sensors	Recording the environment and condition of the robot. Types: Force/torque sensors, IMUs (position/acceleration), 3D cameras, microphones, touch sensors, temperature, position and proximity sensors. Enable balance, object recognition, interaction and safety
Actuator	Convert electrical, hydraulic, pneumatic or piezoelectric energy into motion. Control all joints and axes of movement (arms, legs, hands, head). Decisive for precision, power and speed of movement
Energy supply	Supplies all components with power. Mostly lithium-ion batteries, more rarely supercapacitors or fuel cells. Power management systems optimise runtime and energy efficiency
Control systems	Central computer and decentralised controller (often with real-time operating system) that coordinate sensor technology, actuators and software. Enable complex motion planning, error detection and safe human-robot interaction
Mechanical structure	Skeleton, frame, housing and joints. Lightweight construction with aluminium, carbon fibre or high-performance polymers to reduce weight and save energy. Modularity enables replacement and customisation of segments
Electronics and cabling	Motor controllers, power electronics, signal processing, data buses, communication interfaces. Specialised cables and plug-in connectors for mobility and durability

Software components

Components	Function
Artificial intelligence (AI)	Control of movement planning, perception, speech recognition, object recognition and decision-making. AI models enable learning from data and adaptation to new tasks
Movement planning	Algorithms for path optimisation, balance, gait control and manipulation. Real-time capable systems for safe interaction and efficient motion sequences
Human-robot interaction (HRI)	Voice processing, facial recognition, gesture recognition, emotional AI. Goal: natural and safe communication with people
Security and diagnostic software	Monitors system status, detects errors, controls emergency procedures. Predictive maintenance to avoid failures
Cloud and edge integration	Data processing in the cloud for complex AI tasks, updates and remote monitoring. Edge computing for latency-critical control tasks

Requirements of components

- **Durability:** Components must withstand millions of movement cycles, temperature fluctuations and mechanical loads
- **Freedom from maintenance:** Self-lubricating bearings, durable gearboxes and robust cabling minimise maintenance work and downtimes
- **Weight:** Lightweight construction reduces energy consumption and increases mobility. High-performance polymers and fibre composites are state of the art
- **Costs:** Standardised, scalable components and modular design reduce the total cost of ownership (TCO) and accelerate time to market

Innovative component expertise meets holistic system thinking: igus® – key player for humanoid robotics

With over a decade of active development and integration of plastic components in robotics, igus® has established itself as one of the leading solution providers for moving applications. The company brings its expertise gained from industrial automation, mechanical engineering and low-cost robotics to humanoid robotics.

igus® pursues a clear approach in this respect: The development and production of lubrication-free, low-maintenance and durable polymer components that meet the specific requirements of humanoid robots. As early as 2014, igus® began developing bionic components for robotics and has since built up a comprehensive portfolio of bearing, guide and gearbox systems for a wide range of applications.

Practice-orientated innovative strength

igus® works closely with integrators, manufacturers and developers to make humanoid robotics accessible and affordable for widespread commercial use. The solutions from igus® are designed to work reliably in both prototypes and high volumes – and in demanding environments such as dust, moisture or heavy loads.

Research, test laboratory and service life calculation

The performance of igus® components is continuously checked in our own test laboratory. The wear data obtained there is fed into digital tools for calculating service life, which are available to customers free of charge. This allows the reliability and cost-effectiveness of the components used to be precisely assessed as early as the development phase.

igus® components for humanoid robots

igus® components are specifically designed to fulfil the special requirements of humanoid robotics: They combine durability, freedom from maintenance and cost efficiency with high technical performance. Through the development and continuous optimisation of lubrication-free polymer solutions and modular systems, igus® offers a wide range of components that can be flexibly integrated into a variety of robot architectures: From intricate finger mechanisms to load-bearing structures in arms and legs.

Plain bearings for fingers, joints and actuators

iglidur® plain bearings set new standards for applications such as in the finger mechanics of humanoid robots: They are lubrication-free, maintenance-free, lightweight, extremely cost-effective and available in countless versions. Their durability and resistance make them a key factor for reliable, sustainable and economical robotics solutions.

Lubrication-free: No external lubrication, no maintenance required

iglidur® plain bearings work completely without external lubricants. Solid lubricants incorporated a million times over in the high-performance plastic ensure low-friction running and prevent insufficient lubrication – even with high numbers of cycles and under changing loads. This makes the bearings permanently maintenance-free and minimises the level of services required.

"Practical experience shows that maintenance-free, lightweight and cost-effective components are the key to the widespread introduction of humanoid robots. Our experience confirms that modular, lubrication-free solutions not only keep operating costs down, but also significantly improve the suitability for everyday use and scalability of humanoid systems."

Alexander Mühlens
igus® humanoid robotics expert

Cost efficiency: Up to 89% cheaper than metal bearings

Compared to classic metal plain bearings, iglidur® plain bearings are up to 89% cheaper to purchase. They not only save on unit costs, but also eliminate all expenses for lubricants and maintenance. They therefore enable the economical use of humanoid robots both in the prototype phase and in high volumes.

Lightweight construction: Up to 80% less weight than metal

The light weight of the iglidur® plain bearings contributes to the reduction of the overall weight of assemblies. This enables faster, more precise movements, reduces energy consumption and increases the dynamics and efficiency of the entire robot kinematics.

Design freedom: Over 10,000 sizes, numerous materials

igidur® plain bearings are available in more than 10,000 standard sizes and over 40 material versions. Whether for high temperatures, food contact, chemical resistance or extreme loads – there is a suitable solution for almost every requirement. The processability of plastic also enables particularly compact and intricate mechanisms.

Resistance: Resistant to dirt, dust and chemicals

Thanks to their material properties, iglidur® plain bearings are insensitive to dust, moisture and aggressive media. Even frequent cleaning cycles or use in harsh environments do not impair their function – a clear advantage over metal bearings, where lubricants can be flushed out.

Durability: Tested in the laboratory, service life is accurately predictable

igus® tests all plain bearings in its own laboratory under real conditions. The determined wear data is fed into a free online tool that can be used to calculate the service life for each individual application. This increases planning reliability and minimises the risk of failure.

Sustainability: PTFE-free, PFAS-tested, resource-saving

A number of iglidur® plain bearings are PTFE-free and PFAS-tested – an important aspect in view of current regulatory developments. Dispensing with external lubricants conserves resources and the environment, as no lubricants need to be refilled or disposed of.

Scalability: Can be used economically from single pieces to high volumes

Whether prototype, small series or mass production - iglidur® plain bearings are suitable for any production size. The economic scalability and wide range of types make them the ideal solution for the finger mechanics of modern humanoid robots.

Strain wave gears for elbows and shoulders

The drygear® strain wave gear represents a new generation of robotic joint gearboxes: Compact, lightweight, cost-effective, maintenance-free and easy to integrate. It enables precise, powerful movements in elbow and shoulder joints, legs or other components of humanoid robots and sets new standards for efficiency and reliability in robotics.

Maximum torque density: Compact and powerful for robotic joints

The drygear® strain wave gear has been specially developed for the requirements of humanoid robots where high precision and torque are needed in the tightest installation space. The design is extremely compact and enables integration even in very slim arm and shoulder joints. With a transmission ratio of 28:1 in just one stage, the strain wave gear offers high torque with minimal space requirements – a decisive advantage for achieving complex motion sequences on a human scale.

Lightweight construction thanks to motion plastics: Up to 60% less weight than metal gearboxes

The use of high-performance plastics ensures a particularly light weight. This reduces the inertia of the moving parts and enables faster, more energy-efficient movements. Especially in humanoid robots, where every gram counts, this lightweight design is a clear competitive advantage.

Maintenance-free: Dry operation without external lubrication

The drygear® strain wave gear operates completely lubrication-free. The self-lubricating plastic components eliminate the need for external lubricants and minimise maintenance requirements. The gearbox remains reliable and low-wear even during continuous operation and in demanding environments – ideal for applications where maintenance intervals are difficult to plan or are undesirable.

Direct motor connection: Simple integration and high modularity

The strain wave gear is designed for direct connection to standard motor shafts (e.g. NEMA17). This considerably simplifies the design and assembly of robot arms and enables a modular system architecture. An optional zero position kit (INI kit) can be integrated to simplify initialisation and calibration.

Versatility and scalability: From prototypes to high volumes

Thanks to its compact, modular design, the drygear® strain wave gear is suitable for both individual applications and series production. It can be flexibly adapted to different joint sizes and force requirements, making it ideal for the gradual transformation from prototype to industrial production.



Source: igus®

Corrosion resistance and robustness: For use in harsh environments

The high-performance plastics used are resistant to moisture, dust and many chemicals. This increases the service life of the gearbox and enables it to be used even under difficult environmental conditions - a clear advantage over classic metal gearboxes.

Rod end bearings for arms

igubal® rod end bearings set standards for lightweight construction, freedom from maintenance and cost efficiency in humanoid robotics. They enable dynamic, durable and economical arm designs and thus ensure the competitiveness of modern robot systems.

Ultralight: Up to 80% less weight than metal rod end bearings

igubal® rod end bearings made of high-performance polymer have been developed for applications in humanoid robot arms where every gram counts. Compared to classic metal rod end bearings, they reduce the weight of the arm structure by up to 80%. This enables faster, more dynamic movements, reduces energy consumption and increases the overall efficiency of the robot.

Maintenance-free: Self-lubricating and durable

Thanks to integrated solid lubricants, igubal® rod ends run with permanently low friction and do not require any external lubricants. This makes them completely maintenance-free and prevents failures. Even under high loads and millions of movement cycles, the function remains reliable.

Cost-efficient: Up to 40% cheaper than metal alternatives

Production from polymer enables a considerable reduction in costs. igubal® rod end bearings are up to 40% cheaper than comparable metal rod end bearings. And without compromising on strength or service life. They are therefore suitable for both prototypes and high volume production and make humanoid robotics economically scalable.

Corrosion-resistant and media-resistant

In contrast to metal rod end bearings, igubal® components are insensitive to moisture, dust, chemicals and UV radiation. They do not corrode and they retain their mechanical properties even under adverse environmental conditions. This increases service life and reliability, even with frequent cleaning cycles or outdoor use.

Assembly-friendly: Simple integration and high design freedom

igubal® rod end bearings are ready for assembly, easy to fit and offer a high degree of design freedom. They can be integrated directly into existing structures and enable compact, space-saving designs. This makes them ideal for the complex kinematics of humanoid robot arms.

Versatile: For a wide range of applications and loads

Whether for light, fast movements or high continuous loads – igubal® rod end bearings are available in numerous sizes and versions. They cover a wide range of application scenarios, from intricate finger mechanisms to load-bearing shoulder joints.

Sustainable: PTFE-free, resource-saving production

The rod end bearings are PTFE-free and are manufactured in a resource-saving manner. Their durability and maintenance-free operation reduce material and energy consumption over the entire life cycle.

Low-profile guide systems for arms and legs

drylin® N low-profile guide systems enable compact, quiet and robust linear movements in humanoid robot arms and legs. They are maintenance-free, resilient and easy to integrate.

Compact design: System heights from just 6mm

drylin® N low-profile guide systems have been specially developed for applications with very limited installation space. With system heights of just 6 to 12mm, they enable particularly slim designs – a decisive advantage in humanoid robot arms and legs, where every millimetre counts. The low installation height also supports efficient, transportable system solutions and significantly reduces the overall weight of the mechanical system.

Quiet and maintenance-free operation: Low-noise due to spring pre-load

The low-profile guide systems operate almost silently. This is achieved by the spring pre-load of the carriages and sliding elements, which minimises vibrations and noise. At the same time, the self-lubricating polymer technology ensures permanently maintenance-free operation – without relubrication, without failures, even in 24/7 use. This makes drylin® N the ideal solution for applications where discretion and reliability are required, for example in service and assistance robots.

Robustness: Resistant to dirt, impact and corrosion

drylin® N low-profile guide systems are insensitive to dirt, dust and moisture. The high-performance polymers and aluminium profiles used are corrosion-free and retain their running properties even under harsh conditions. Shocks or vibrations, as they occur in the mobile use of humanoid robots, do not impair their function – a clear advantage over classic metal guides.



Source: igus®



Source: igus®

Energy efficiency and easy assembly

The light weight and low-friction design reduces the energy required for movements. Assembly is quick and straightforward thanks to a handful of components. Overmoulded carriages and prefabricated double carriages further reduce the assembly work required and enable flexible adjustments during the development process.

Wide range of designs and options

drylin® N low-profile guide systems are available in various lengths, widths and designs. They can be customised to the requirements of robot arms and legs – from delicate grippers to load-bearing leg axes. The high level of modularity facilitates integration into a wide range of robotics designs.

Linear guides for modular, robust robot mechanics

drylin® W linear guides from igus® are robust and maintenance-free linear guide systems that have been specially developed for flexible and modular design solutions. They are widely used in automation applications, robotics and mechanical engineering, including in humanoid robot systems.

Maintenance-free and lubrication-free

drylin® W linear guides do not require any external lubrication. The sliding elements made of high-performance polymer contain solid lubricants that enable low-friction and long-lasting dry operation. This makes the system particularly low-maintenance and prevents the formation of films of dirt caused by lubricants.

High flexibility and a wide range of types

The modular system offers numerous single rails, double rails, curved profiles and different types of carriage. Over 50 different profiles, numerous linear plain bearings and carriages are available. This means that the system can be easily adapted to a wide range of requirements, for example as a load-bearing axis in robot legs or as a component in modular robot arms.

Lightweight construction and high stability

The rails are predominantly made of hard-anodised aluminium, which ensures lightweight and high corrosion resistance. Variants with extremely lightweight carbon rails are available for particularly weight-optimised applications, such as in mobile robots or robot-assisted gripper systems.

Robust and resistant to dirt

The guide systems are resistant to dirt, dust, moisture and chemical influences, making them ideal for applications in harsh environments and hygienically sensitive areas. Even in applications that require regular cleaning or disinfection, the running properties are maintained.

Simple assembly and customisation

The system is designed for quick and uncomplicated assembly. Rails and carriages can be installed without special tools or alignment. Parallel single rails or double rails enable flexible design solutions.

Low-noise, long-lasting operation

The system runs very quietly thanks to the sliding effect of the polymer bearings. Miniature versions in installation size 06 are particularly suitable for extremely compact installation spaces, such as those found in robotic hand and finger mechanisms. At the same time, larger versions can accommodate loads of up to 2 tonnes.

Typical areas of application in robotics

- Load-bearing axes in humanoid robot legs
- Modular arm structures and adjustment units
- Mechanics of gripper systems and axis combinations
- Integration in mobile robots thanks to lightweight carbon profiles

With these properties, drylin® W linear guides offer a universal, durable and cost-effective solution for demanding linear movements and mechanical structures in modern robotics.

Lead screw technology for precise linear movements in robotics

dryspin® lead screw technology from igus® was developed for the efficient conversion of rotary movements into high-precision linear movements. It is particularly suitable for applications in humanoid robot hands, grippers, finger mechanisms and other linear axis systems where freedom from maintenance, compact design and long-lasting performance are required.

Lubrication and maintenance-free

The dryspin® lead screw technology is based on a patented combination of plastic nut and stainless steel or aluminium lead screw. All nuts are made of wear-resistant high-performance plastics that are self-lubricating. External lubricants or regular maintenance work are not required – an advantage in the continuous operation of autonomous robots and where no contamination from lubricants may occur.

Long service life and high efficiency

An optimised, asymmetrical thread geometry increases the contact surface of the tribologically improved polymer in the nut. Compared to traditional trapezoidal threads, this results in a service life that is around 30% longer and an efficiency of up to 82%. The geometric design also ensures less wear and lower frictional resistance.

Quiet, vibration-free operation

Rounded tooth flanks reduce the contact surface as well as vibrations and result in very quiet operation – crucial for robot applications in sensitive areas, e.g. in the service sector, care or for cases of human-robot collaboration.

Versatility and design options

dryspin® lead screw technology is available in a variety of diameters (4 to 50mm), pitches (0.5 to 100mm) and types. Trapezoidal, metric and ACME threads as well as the patented high-helix geometry are standard. Demanding loads, high speeds and minimal installation space – dryspin® offers maximum flexibility for a wide range of robot kinematics.

Further advantages

- 100% corrosion-free, even in damp or aggressive environments
- Quiet and vibration-damping thanks to special tooth flanks
- Lead screw nuts are available in various materials and types for special requirements (e.g. locating spigot, flange, compact)
- Lower energy consumption compared to classic metal solutions, as less drive power is required

Bar stock for customised components

iglidur® bar stock products enable the development of wear-resistant, maintenance-free and customised components for humanoid robots. The combination of material diversity, design freedom and sustainability makes them a key resource for innovative, durable and economical customised components in modern robotics.

Variety of materials: over 40 materials for every requirement

iglidur® bar stock products offer developers and designers an exceptional selection: More than 40 different materials are available, from high-temperature and chemical-resistant variants to food-safe and electrically conductive materials. Each material is optimised for moving applications and enables targeted adaptation to specific requirements – such as high sliding speeds, extreme loads or special environmental conditions.

Maximum wear resistance: For durable and maintenance-free solutions

The bar stock products are made from the proven iglidur® materials, which are characterised by extremely low coefficients of friction and outstanding wear resistance. They are specially developed for applications with millions of movement cycles and enable the construction of components that function reliably even under continuous load – without relubrication and with minimal maintenance.

Maximum design freedom: Round bars, plates, hollow rods, sheets, strips and individual cut-to-size parts

iglidur® bar stock products are available as round bars, plates, hollow rods, sheets and plate strips. Special cut-to-size parts and customised profiles are possible at any time. This allows developers to respond precisely to the geometry and design requirements of their humanoid robots – from intricate finger mechanisms to large structural elements.

Self-lubricating and PTFE-free: Sustainable and future-proof

All iglidur® bar stock products are self-lubricating, require no external lubricants and are PTFE-free as well as PFAS-tested on request. This reduces maintenance work, conserves resources and fulfils current regulatory requirements for sustainable materials.

Certified quality: Production in accordance with DIN EN 15860

All iglidur® bar stock products are manufactured according to DIN EN 15860. This standard guarantees consistent quality, tight tolerances and tested material properties – an important factor for high-volume production and safety-relevant applications in robotics.

Innovation example: Iggly Rob – the humanoid robot from igus®

What happens when a component manufacturer like igus® decides not only to supply components, but also to consistently put holistic system thinking in practice itself? With Iggly Rob, igus® has taken precisely this step, thereby creating a platform that is more than just a technical feasibility study. Iggly Rob is a living experiment that poses the question: How can the vision of a humanoid robot be put into practice without sacrificing flexibility, cost-effectiveness or suitability for everyday use?

Modularity that sets new standards

Iggly Rob is not a rigid prototype. Its architecture is open, modular and designed to be constantly rethought. The arms are based on modular cobots that can be retooled in just a few minutes – an approach that offers real advantages in an industry where requirements and applications are changing rapidly. The mobile base makes it possible to access different workstations without the robot being restricted to a fixed location.



Source: igus®

In practice, this means:

- Companies can use Iggy Rob to test new applications without having to commit to a rigid system architecture.
- Developers and integrators are provided with a flexible test field to test interfaces, components and software updates quickly and without risk.
- Customers experience how humanoid robotics can be integrated into their real working day –and where conventional systems reach their limits.

Proven suitability for everyday use

The aim of igus® is not only to demonstrate technical feasibility with Iggy Rob, but also to prove its suitability for everyday use. How robust are components when they are cleaned daily or used in shift operations? How do users react when a humanoid robot takes over routine tasks? What requirements arise when a system really has to be available around the clock? Iggy Rob is not looking for laboratory conditions, but for the real world and thus provides answers that are relevant for the further development of the entire industry.

Economic efficiency and sustainability as guiding principles

A key objective: To demonstrate the economic feasibility of humanoid robotics. Iggy Rob relies on standardised, cost-effective components and a modular architecture that enables a fast return on investment. The platform is designed so that it can be operated with minimal maintenance – a decisive factor for the broad acceptance of humanoid systems in industry and the service sector.

Diverse fields of application, real insights

Whether used in the care sector, industrial assembly or as a learning platform in education – Iggy Rob shows how humanoid robotics can be flexibly adapted to new tasks. Each application brings new findings and requirements that flow directly into the next iteration. This creates a cycle of innovation, practical testing and further development that goes far beyond traditional product development.

What Iggy Rob means for the industry

Iggy Rob is not an end product, but a statement: The future of humanoid robotics will not be decided in the laboratory, but in real-life applications. For decision-makers, developers and users, Iggy Rob offers a blueprint for how modularity, cost-effectiveness and practicality can be combined and how components can be turned into real solutions that can permanently change everyday life and the world of work.

Opportunities and challenges: A changing market

The market for humanoid robots is at a turning point. Forecasts show exponential growth: According to MarketsandMarkets, the global market will grow to over USD 13 billion by 2028, with annual growth rates of more than 40%. These figures are confirmed by current scientific analyses, which expect particularly dynamic growth in Europe and the Asia-Pacific region. The fields of application range from industrial automation and logistics, care, education and research to service, entertainment and security applications.

Opportunities

Flexibility and adaptability

Humanoid robots can take on tasks that were previously considered difficult to automate – especially where human mobility, interaction and social intelligence are required.

Demographic change

The ageing society and the shortage of skilled labour are increasing the demand for assistance robotics and flexible automation solutions.

Technological innovation

Advances in AI, sensors, actuators and materials science are opening up new possibilities for efficiency, safety and sustainability.

New business models

The integration of humanoid robots creates space for innovative services and products – from personalised customer interaction to data-based process optimisation.

Challenges

High investment and development costs

The development of complex humanoid systems remains cost-intensive and requires in-depth technological expertise.

Regulation and acceptance

Safety standards, data protection and ethical issues are key hurdles to a broad market launch.

System integration and scalability

Seamless integration into existing processes and economic scaling are crucial for long-term success.

Market education

Many end users are still unfamiliar with the potential and limitations of humanoid robotics – education and pilot projects are needed to create acceptance and trust.

igus® – partner on an equal footing for developers and integrators

igus® brings decades of experience in the development of lubrication-free, low-maintenance and durable polymer components to humanoid robotics. Our company understands the challenges of the industry first-hand – from material selection and service life calculation to integration into complex systems.

Your advantages with igus®

Cost efficiency:

Components such as iglidur® plain bearings are up to 89% cheaper than metal alternatives and significantly reduce operating costs.

Durability and freedom from maintenance:

Self-lubricating materials minimise downtimes and maintenance costs.

Lightweight construction and design freedom:

Up to 80% lighter than metal – ideal for dynamic, energy-efficient robot solutions.

Broad portfolio:

Over 40 materials, more than 10,000 sizes and customised bar stock enable tailor-made solutions for every application.

Practical innovation:

With Iggy Rob, igus® proves how component expertise, system integration and practicality can be combined – from the initial idea through to actual use.

Contact our igus® experts

Would you like to promote humanoid robotics at your company?
Are you looking for components that will make your development more economical, sustainable and reliable?

Talk to our igus® experts. Together we will find the right solution – from the initial feasibility study to series integration.

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► [To contact page](#)

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The terms "Apro", "autochain", "CFRIP", "chainflex", "Chainge", "chains for cranes", "conprotect", "cradle-chain", "CTD", "drygear", "drylin", "dryspin", "dry-tech", "dryway", "easy chain", "e-chain", "e-chain systems", "e-ketten", "e-kettensysteme", "e-loop", "energy chain", "energy chain systems", "enjoyneering", "e-skin", "e-spool", "fixflex", "flizz", "i.Cee", "ibow", "igear", "igidur", "igubal", "igumid", "igus", "igus improves what moves", "igus:bike", "igusGO", "igutex", "iguverse", "iguversum", "kineKIT", "kopl", "manus", "motion plastics", "motion polymers", "motionary", "plastics for longer life", "polymore", "print2mold", "Rawbot", "RBTX", "RCYL", "readycable", "readychain", "ReBeL", "ReCyyole", "reguse", "roboLink", "Rohbot", "savfe", "speedigus", "superwise", "take the dryway", "tribofilament", "tribotape", "triflex", "twisterchain", "when it moves, igus improves", "xirodu", "xiros" and "yes" are legally protected trademarks of igus® SE & Co KG / Cologne in the Federal Republic of Germany and possibly in some foreign countries. This is a non-exhaustive list of trademarks (e.g. pending trademark applications or registered trademarks) of igus® SE & Co. KG or affiliated companies of igus® in Germany, the European Union, the USA and/or other countries or jurisdictions.

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