TQ WHITEPAPER Humanoid Robots Owner's Manual

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Product Usage Instructions

Overview

The humanoid robot actuators from TQ are designed to provide human-like movements in robotic hardware. These motors are crucial components for achieving versatile and precise motions in humanoid robots.

Factors for Selecting Motors

The selection of motors for humanoid robot joints is crucial for achieving human-like movements. Key factors to consider include precision, torque, and rotational speeds. TQ's torque motors are specifically designed to meet these requirements.

Precision and Pole Pair Count

The precision of the electric motors is directly influenced by the number of pole pairs. TQ's servomotors emphasize a high pole pair count to ensure precise control, positioning, and regulation in humanoid robots.

Installation and Maintenance

When installing the actuators, ensure proper alignment and secure mounting to prevent misalignment issues during operation. Regular maintenance checks are recommended to ensure optimal performance and longevity of the motors.

FAQs

- **Q: What are the primary applications of humanoid robots?**
  - A: Humanoid robots are particularly promising in production and logistics, especially for labor-intensive, physically demanding, and repetitive tasks.
- **Q: How do torque motors contribute to human-like movements in robots?**
  - A: Torque motors provide high torque at low rotational speeds, enabling precise and controlled

movements essential for replicating human-like motions.

PRODUCT INFORMATION

WHITEPAPER

The drive behind the movement Frameless torque motors for humanoid robots – your guide to successful selection and implementation

humanoid robots

The Next Evolutionary Stage in Robotics: Humanoid Robots

Humanoid robots, with their ability to mimic human form and movement, represent the next evolutionary stage in robotics and carry a unique fascination. These robots feature a human-like shape, equipped with jointed limbs – referred to as degrees of freedom – and can operate autonomously through artificial intelligence control, with capabilities in fine motor skills and machine learning. All these abilities make humanoid robots highly versatile, although their deployment currently involves higher costs compared to cobots and industrial robots. Additionally, humanoid robots are typically modular in design, facilitat-ing maintenance, repairs, and upgrades.1

Humanoid Robot TALOS by PAL Robotics © PAL Robotics

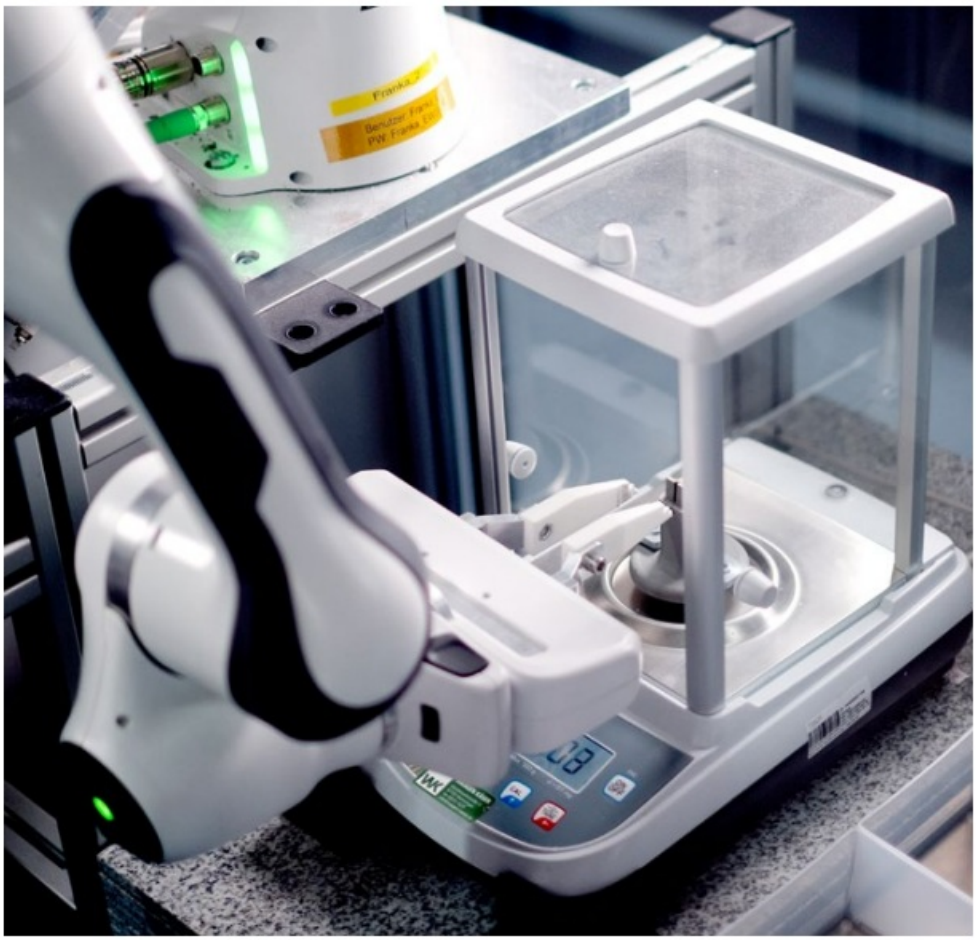
Race to Commercialization

Market Opportunities and the Race to Commercialization

The race to develop the first commercially viable humanoid robot is one of the most exciting trends in the tech world. According to analyses by the investment bank Goldman Sachs, the market for humanoid robots could reach a volume of $35 billion by 2033. This impressive figure highlights the vast potential of this technology for the future.2

Currently, numerous companies worldwide are working on humanoid robots for commercial use, with many of them sourcing servomotors from TQ for this purpose.

A market analysis by management consultancy Horváth from March 2024 projects that the first human-like robots could enter serial production for industrial use as early as 2025. Their applications are particularly promising in production and logistics, especially for labor-intensive, physically demanding, and repetitive tasks.3



Cobots and industrial robots are well suited for simple, repetitive tasks.

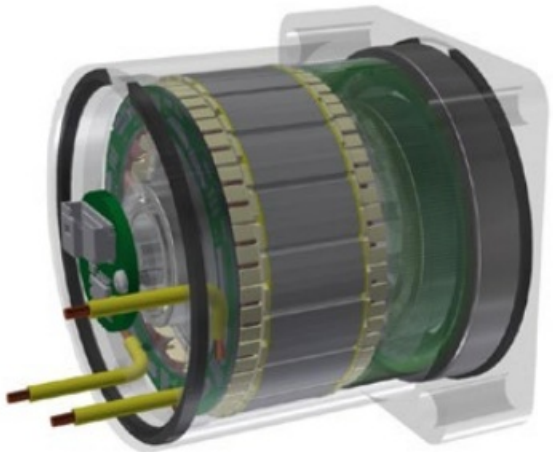
Actuators

The Key to Human-Like Movement in Robotics Hardware

In terms of hardware, actuators play a crucial role in achieving human-like movements in humanoid robots. These components act as the robotic equivalent of human joints and muscles, enabling both rotational and linear movements within a system. Actuators are composed of a combination of gears, motors, sensors, bearings, and encoders. The more degrees of freedom required, the more actuators are needed. Currently, humanoid robots

under development are capable of achieving between 16 and 60 degrees of freedom. As development progresses, humanoid robots will require even more actuators to allow for greater freedom of movement, accommodating increasingly complex applications. Hardware concepts can vary significantly based on specific requirements for movement range, hand design, sensor sensitivity, and other factors.4 The humanoid robotic body primarily consists of actuators, along with supporting systems such as sensors, bat-tery packs, structural components, and cooling systems. The next section provides an overview of the requirements a humanoid robot's motor must meet to enable human-like movement.4

The origin of RoboDrive technology lies in the Institute of Robotics and Mechatronics at the German Aerospace Center (DLR). With their large hollow shaft and frameless, lightweight design, these motors are ideally suited for robotic drive modules.



Rotary actuator for a robot joint

Humanoid Robot Joints

Factors for Selecting Motors for Humanoid Robot Joints

Human-like movements can be controlled using electric, hydraulic, or pneumatic drive systems. Currently, the predominant practice is to use specific actuators consisting of a gearbox, torque motor, encoder and motor controller. Torque motors are high-pole, electric motors that provide high torque at relatively low rotational speeds.

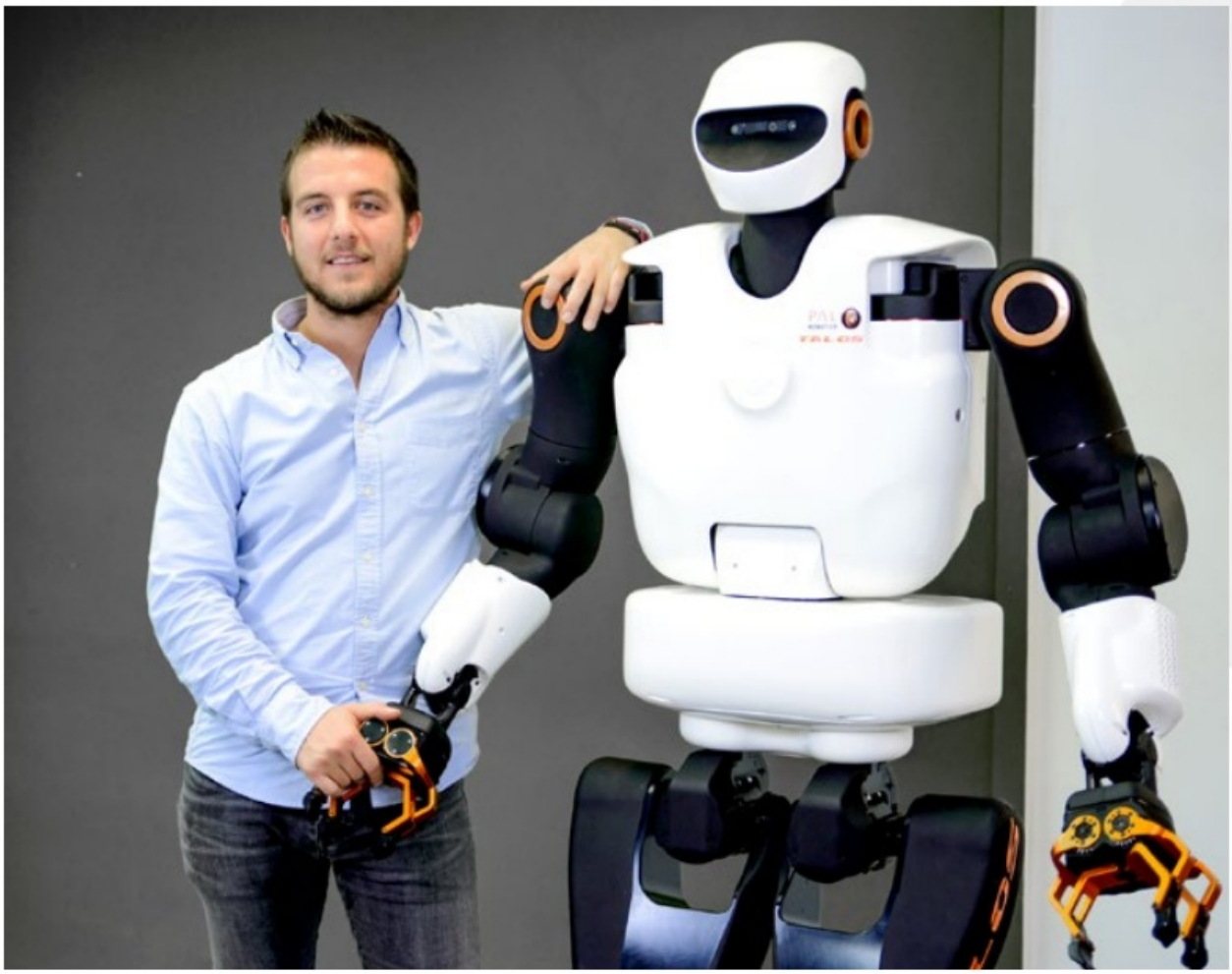
The following outlines the system requirements that are crucial for motor selection in a humanoid robot.

Precision

For a robot to perform controlled, fluid, and versatile movements, motor precision is critical. The more precise the drive, the more direct the connection between the robot's movement and its "visual process," which includes sensors and camera technology. Each joint is defined by three-dimensional vectors, and for maximum accuracy, it is essential that the motors – especially when combined across multiple joints – consistently achieve the "correct" position. Even minor deviations in individual joints, such as the hip, knee, and ankle, can accumulate, leading to significant misalignments. The precision of an electric motor increases with the so-called pole pair count, a key factor influencing motor behavior, as it directly impacts control, positioning, and regulation. In designing their frameless servomotors, the TQ-Group places a strong emphasis on achieving a high pole pair count. TQ's client, PAL Robotics, also understands that precision is a decisive factor for the commercial success of a humanoid robot.

The precision of an electric motor increases with the number of pole pairs.

"TQ electric motors offer highly precise position and torque control across a wide range of conditions, from low speed and high torque to high speed and low torque. This is essential for the natural, fluid movements expected of humanoid robots. This consistency is especially valuable in environments where robots interact with humans, enhancing the acceptance of the technology."



Chief Technology Officer Luca Marchionni, PAL Robotics with TALOS. © PAL Robotics

(From left to right) Robert Vogel and David Hastings, TQ-Group, with Jonathan Hurst, Chief Robot Officer, Agility

Response Time and Dynamics

- The environment in which humans – and consequently humanoid robots – move is volatile and constantly changing. Motors must be able to respond and adapt quickly to any environmental shift (e.g., if a robot steps into an unexpected hole or encounters a shifting surface). For a humanoid robot to react flexibly and rapidly to changes, it needs exceptional dynamic control, precise manageability, and fast response times. The dynamics of an electric motor refer to its ability to respond quickly and accurately to changes in load or control input. This dynamic capability is essentially how well a motor can adjust its speed, position, or torque under varying conditions. Maintaining a robot's stability during movement, such as walking, running, or performing complex tasks, requires a dynamic balance. This involves advanced control strategies to adapt instantly to rapidly changing conditions. Agility Robotics, a manufacturer of humanoid robots, demonstrates in a video how critical jointed legs are for humanoid functionality in diverse environments.
- How does an electric actuator achieve such high response time and dynamics? To react in real-time, very high torque is needed briefly, such as when adjusting a foot movement to align with an unexpected hole in the ground. This torque is shortly increased several times over, a capability referred to as the overload capacity of a servomotor or peak torque – i.e., the maximum torque a motor can generate for a short duration. The peak torque of TQ motors is approximately three times higher than their nominal torque or the continuous torque sustainable over long periods. Specifically, TQ motors achieve a peak torque in the double-digit New-ton-meter (Nm) range, providing industry-leading over-load capacity.

Jonathan Hurst of Agility Robotics illustrates in this video the applications where legs are particularly advantageous for humanoid robots.

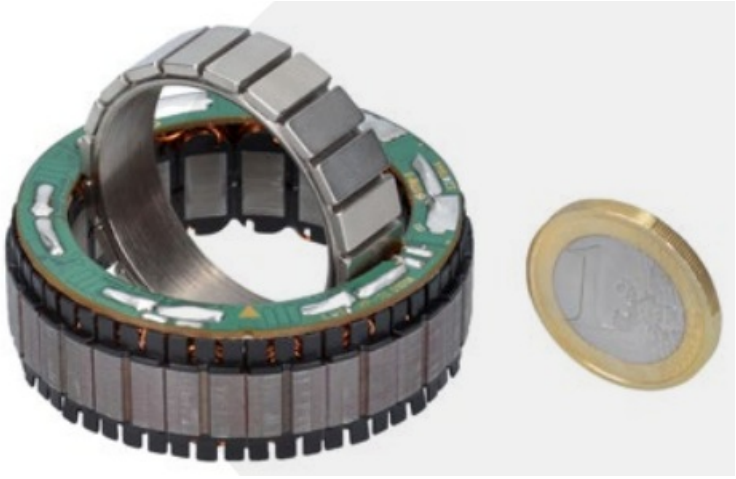
Thanks to unique winding technology, TQ motors achieve very low copper losses.

Efficiency and Power Consumption

Efficiency – specifically, the amount of power loss over battery life – determines how long a battery-powered humanoid robot can operate. High efficiency, achieved through low copper losses, directly extends battery life. Copper losses refer to energy losses caused by the electrical resistance in a motor's windings, which dissipate as heat and are one of the primary sources of energy loss in electric machines. Motors with high power losses consume more electricity, which reduces battery life and consequently limits operational time. This means that efficiency is a much more critical factor for mobile, battery-powered humanoid robots than for collaborative robots (cobots) that are connected to a power source. In practical applications, such as in industry, healthcare, or retail, high efficiency is essential for the continuous operation of humanoid robots. TQ torque motors achieve an efficiency of 90 percent or higher, with particularly low copper losses measured in watts. These values are typically specified in datasheets as efficiency or copper losses at room temperature.

Torque Density and Compactness

The torque density of an electric motor is a measure of how much torque the motor can generate per unit of volume or weight. Torque density is a crucial factor for the performance and compactness of a motor, especially important in applications where weight is critical – such as in robotics. The overall weight of a humanoid robot is largely determined by the weight of its joints. The lighter the motors in these joints, the lower the total weight, which has a positive impact on battery life, payload, and dynamics. In the industry, this weight factor is often referred to as "muscular."



- TQ motors are exceptionally lightweight and power-dense, allowing robotics manufacturers to significantly reduce weight and installation space while maintaining consistent performance.

Additional weight is a disadvantage for a humanoid robot, as a leaner design enhances dynamism, speed, and especially the ability to carry heavier payloads. TQ customer PAL Robotics cites this weight advantage as a key reason for choosing TQ's inner rotor motors (ILM).

- "We chose ILM motors because they offer an unmatched torque-to-weight ratio. TQ motors have the highest copper fill factor on the market. It is physically impossible to fit more copper within each motor size." Luca Marchionni, CTO, PAL Robotics

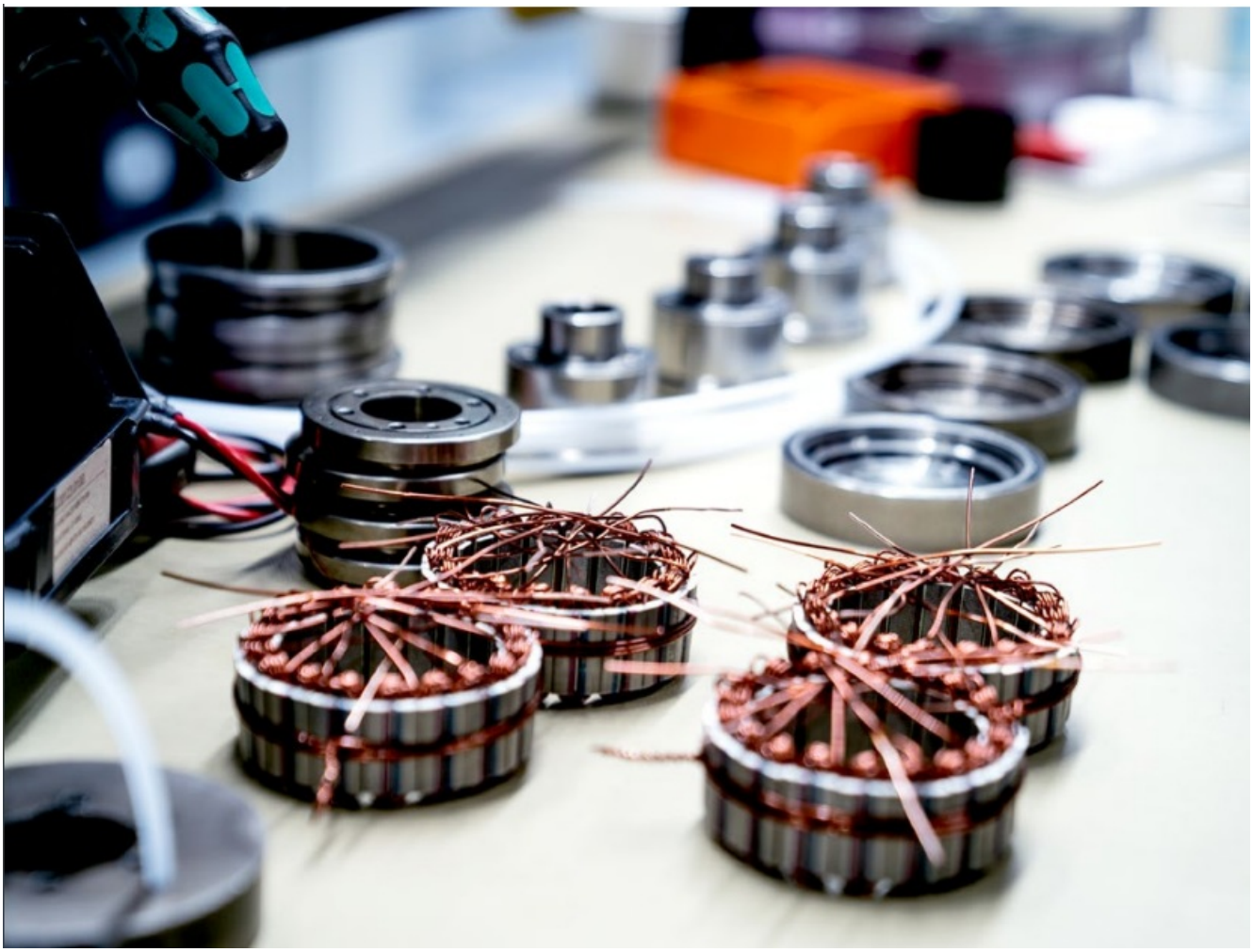
Luca Marchionni, CTO of the Spanish robotics company founded in 2004, explains: "We chose ILM motors because they offer an unmatched torque-to-weight ratio. The available motor sizes and configurations were a perfect fit for the requirements we faced in designing various robot joints, from the ankle to the neck. […] TQ's

frameless servo kits allow us to minimize mechatronic integration, as one of our main goals is to keep the volume and weight of our robots as low as possible. An additional advantage of these motors is their large hollow shaft, which is crucial for routing cabling internally and achieving a clean robot design.” TQ motors stand out for their exceptional torque density compared to other motors, meaning they can deliver twice the torque at the same size or achieve the same torque at half the size. TQ accomplishes this through a unique winding technology that maximizes the copper fill factor compared to conventionally wound electric motors. Currently, TQ is the only motor developer on the market that, thanks to specialized manufacturing processes, fully capitalizes on the physical limits of copper fill: in each motor size, it is physically impossible to fit any more copper. This gives TQ motors the highest copper fill factor on the market.

Together with the DLR, TQ succeeded in developing a new motor technology with the highest power density and torque relative to weight and volume.

The compact design of the drive system enables efficient use of space and weight reduction, lowering the robot’s center of gravity and enhancing stability. For example, in a busy warehouse in a densely populated urban area or on an assembly line, the compact design allows the robot to navigate tight spaces effectively and maintain balance when maneuvering through crowded areas.

TQ motors have the highest copper fill factor on the market. Within each motor size, it is physically impossible to add more copper.



Robustness and Reliability

The robustness and reliability of motors are also crucial factors in humanoid robotics applications. Especially during the testing phase, robots are prone to frequent falls. A robust, maintenance-free design ensures that joints remain intact and functional throughout the learning curve. Motors face the greatest challenges in space, where they must operate reliably under temperature fluctuations from -40°C to +125°C (-40°F to +257°F). On the ISS (International Space Station), a TQ ILM-E motor was used in the arm of the ROKVISS robot, performing precise tasks in zero gravity – consistently and with high performance over five years and hundreds of tests.

The TQ motors were used in the robotic arm ROKVISS, which conducted around 500 successful tests over several years on the International Space Station (ISS). In industrial application scenarios, such as in a production or warehouse environment, a humanoid robot tasked with lifting heavy loads may occasionally drop items or be subjected to sudden impacts. The robustness of the robot's joints protects against damage, ensuring continuous and reliable operation even under challenging conditions.

Manufacturing of Humanoid Robots

Other Relevant Factors for the Successful Manufacturing of Humanoid Robots

Series Production and Motor Integration in Design

Given the significant market potential forecasted for humanoid robotics, easily implemented motor integration into custom designs is a crucial factor for robot manufacturers aiming to transition from prototype to series production successfully. "With TQ, we have found a fantastic partner in terms of quality and support. TQ's technical team assists us in selecting motor kits and reviewing the design, ensuring optimal integration between mechanical parts and motor kit components," says Marchionni from PAL Robotics.

- TQ is more than just a motor supplier: TQ often integrates its motors directly into custom housings for clients. This means TQ not only provides motors and complete development projects for entire motor-gear units but also specializes in integrating its motors into client-specific housings.
- For a prominent U.S. manufacturer of humanoid robots, TQ customizes motors with a dedicated wiring board, simplifying integration and connection with the power electronics. Here, TQ's extensive expertise from over 30 years of electronics development proves invaluable.

TQ supports customers from motor supply and housing integration to the development of complete motor-gear units – all from a single source.

Standard Motors or Customized Solutions?

Robotics manufacturers often face the decision of choosing a motor supplier that provides standard components or opting for a custom solution. At TQ, customers can select from a range of standard sizes, which we tailor to specific applications if needed. The advantage of TQ's frameless servo kits is their flexibility in diameter and stack length, allowing customizing performance and dimensions for the application. Especially for production volumes of more than a hundred units per year, a custom solution can be the best option, providing full control over design, materials, and the manufacturing process.

TQ is one of the few providers in Germany capable of industrializing complete robots, a capability it has already demonstrated successfully.

Hardware is Hard

The saying “Hardware is hard” aptly applies to the development and production of robotic joints and their required components. The core competencies and history of some humanoid robotics manufacturers lie in artificial intelligence and software, while expertise in the industrialization of robots and the development of mechatronics is less common. Additionally, the complexity of developing and producing systems like robotic joints is often underestimated.

In this context, it can make sense to rely on technology leaders in their respective fields. Amongst other things, TQ develops complete motor-gear units for mobile applications.

- Sensodrive, a manufacturer of ro-botics drive modules and winner of the Innovationspreis Bayern 2024, is helping to significantly reduce the time-to-market in the development of medical robots.
- Complete drive systems can also save valuable time in the current race to create the first mass-produced humanoid robot.

Sensodrive manufactures certified complete drive systems, incorporating TQ’s frameless motors. © Sensodrive

About the Author

Robert Vogel is Sales & Business Development Manager in the TQ-Ro-boDrive division, which develops and produces customized drive systems for demanding applications. An industrial engineer, Robert Vogel has over 20 years of experience in the automation and robotics industries.

TQ location in Inning am Ammersee

The technology company TQ-Group offers a complete range of services, from development, production, and service to product lifecycle management. These services cover assemblies, devices, and systems, including hardware, software, and mechanics. TQ offers services tailored to their specific needs. Standard products, such as ready-to-use microcontroller modules, drive, and automation solutions, further enhance the service offering.

The TQ-Group employs around 2,000 people across its locations in Delling, Seefeld, Inning, Murnau, Peissenberg, Peiting, Durach in Allgäu, Wetter an der Ruhr, Chemnitz, Leipzig, Fontaines (Switzerland), Shanghai (China), and Chesapeake (USA).

CONTACT INFORMATION

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MORE INFORMATION

References:

- www.horvath-partners.com/de/media-center/studien/humanoide-roboter-inoperations
- www.goldmansachs.com/intelligence/pages/the-global-market-for-robots-could-reach-38-billion-by-2035.html
- www.horvath-partners.com/de/media-center/studien/humanoide-roboter-inoperations
- Morgan Stanley & Co. LLC: Humanoids: Investment Implications of Embodied AI (June 26, 2024)

Documents / Resources

	TQ WHITEPAPER Humanoid Robots [pdf] Owner's Manual WHITEPAPER Humanoid Robots, WHITEPAPER, Humanoid Robots, Robots

References

- Group Publishing
- RoboDrive | Innovative Antriebstechnik | TQ
- Humanoide Roboter inOperations - Horváth
- User Manual