VOLUME 1:
Head &
Vision Systems

CONNECTING THE FUTURE

Designing Connectivity for Head & Vision Systems

Connector Strategies for High-Speed Vision, Motion, and AI-Driven Robotics

HIROSE ELECTRIC AMERICAS

Connector Solutions for Today's Challenges — & Tomorrow's Needs

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CONNECTING THE FUTURE

Engineering Connectivity for Humanoid Head & Vision Systems

Humanoid robots may appear lifelike on the outside, but the real complexity lies inside the head assembly. **Cameras, LiDAR sensors, microphones, displays, and motion actuators** must operate together within a compact structure that is constantly in motion. These subsystems generate **large volumes of high-speed data** while sharing limited power, space, and thermal capacity.

Designing the interconnect architecture that supports these humanoid systems is a **critical engineering challenge,** directly influencing **signal integrity, mechanical stability, serviceability, and long-term system reliability** in real-world conditions.

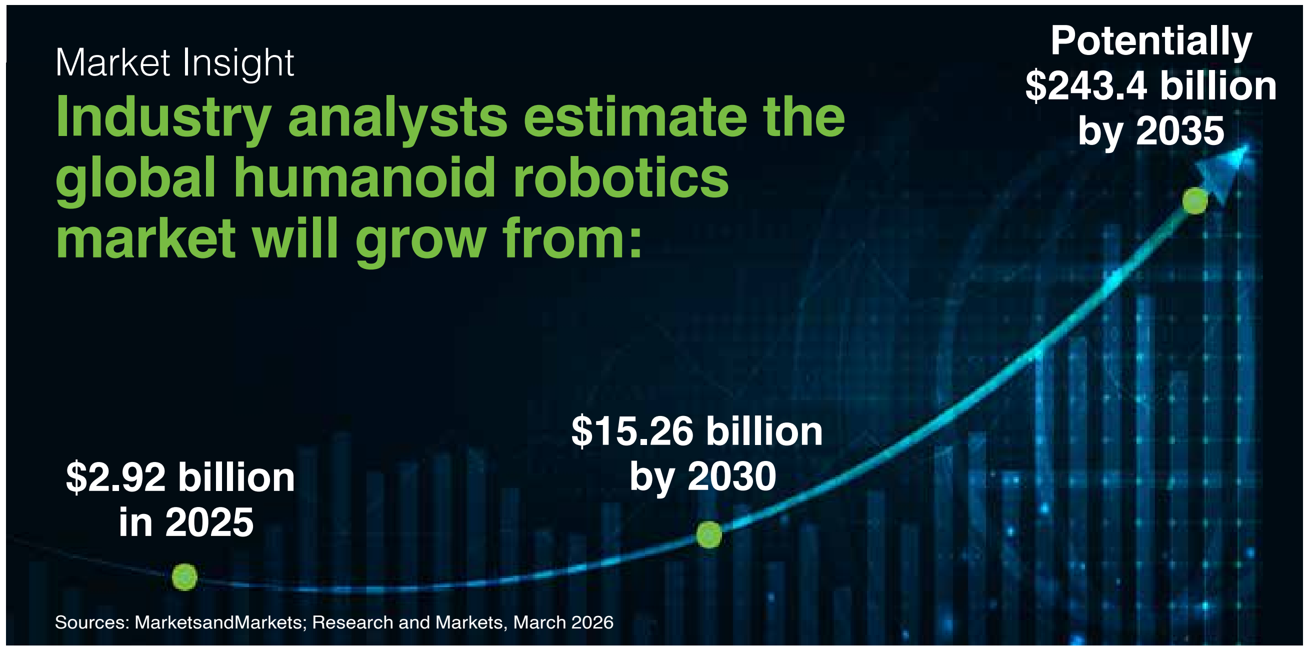
> **ENGINEERING INSIGHT**
>
> **Sensors and AI define capability, but interconnect architecture determines whether those systems operate reliably under real-world motion, vibration, and integration constraints.**

Key Elements of a Humanoid Robotic Head Assembly

Hirose connector solutions support these architectures by enabling reliable signal and power distribution across tightly integrated, motion-driven subsystems within the head assembly.

From Research Labs to Industrial Pilots

After years of research prototypes and demonstration systems, manufacturers are beginning to move toward commercial pilots and early production-scale deployments. Industry investment reflects this shift. Funding in humanoid robotics **exceeded $9.8** billion by 2025, reflecting growing confidence in embodied AI systems. In 2026, Apptronik raised **$520 million** backed by Google and Mercedes-Benz to expand deployment of its Apollo humanoid robot in manufacturing environments. *(Source: Research and Markets, March 2026)*



Example deployments already underway include:

- **Automotive manufacturing pilot programs at Mercedes-Benz & BMW**
- **Warehouse and logistics trials through companies such as GXO**
- **Industrial material-handling deployments across global supply chains**

These programs represent a transition from experimental robotics platforms to **systems designed for real operational environments.**

Industry Reality:
Four Barriers to Humanoid Scale

Humanoid robotics still faces several engineering constraints that limit large-scale deployment, including the cost of dexterous manipulation systems, limited battery energy density, and the challenge of manufacturing precision mechanical components at volume.

(Source: Research and Markets, March 2026)

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At the system level, these challenges translate into four critical design barriers:

1 Certified Fenceless Safety

Humanoid robots must operate safely alongside humans without physical safety barriers. This requires reliable sensing, control systems, and communication between distributed electronic components.

Connector Considerations:
Stable signal transmission, robust shielding, and secure mating help ensure reliable communication between perception systems, control electronics, and safety-critical subsystems.

2 Sustained Multi-Shift Uptime

Industrial deployments require robots capable of operating continuously across extended production schedules.

Connector Considerations:
Durable interconnects must maintain reliable electrical performance under vibration, motion, and thermal cycling across long operational periods.

3 Reliable Dexterity & Mobility

Humanoid robots must perform complex manipulation tasks while maintaining balance and coordinated movement.

Connector Considerations:
Compact connector solutions support dense integration of sensors, actuators, and control electronics while maintaining stable electrical connections in moving assemblies.

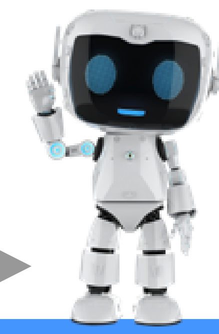
4 Cost Reduction at Scale

For humanoid robotics to scale commercially, system cost must decline while reliability remains high.

Connector Considerations:
Connector solutions designed for compact layouts, simplified wiring architectures, and manufacturable assembly processes help reduce system complexity and long-term maintenance costs.

Engineering Reality:
Integration Is the Hardest Problem

INSIDE THESE SYSTEMS:



Sensors generate perception data

Actuators control movement and balance

Processors interpret sensor input

Control systems coordinate motion and interaction

All of these subsystems must exchange data in real time while the robot walks, balances, and manipulates objects. This places strict demands on maintaining **reliable electrical connections** across moving assemblies.

As humanoid robotics programs move from prototypes to real-world deployment, system integration has emerged as a primary engineering challenge. Companies developing advanced humanoid platforms, including **Boston Dynamics, Tesla, and Figure AI,** are building systems that integrate thousands of mechanical and electronic components operating continuously in motion.* These platforms **combine perception, actuation, processing, and control** into tightly coordinated systems that must function reliably in real time. *(Source: McKinsey & Company)*

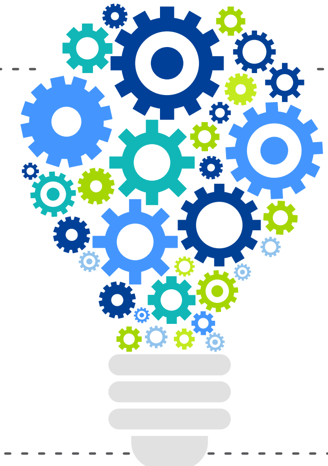
McKinsey & Company, The Next Act for Robotics: Human–Machine Collaboration

System Architecture:
Inside the Humanoid Robotic Head

The head assembly is one of the most densely **integrated and mechanically active** areas of a humanoid robot. Vision sensors, microphones, displays, and motion mechanisms **must operate together within a compact structure** that supports continuous movement and real-time processing.

Unlike stationary electronics, these **subsystems must maintain stable electrical connections** while the head continuously moves, repositions, and responds to its environment.

Multiple subsystems share limited space while exchanging **high-speed data between sensors, processors, and control electronics.** This creates competing demands between routing density, signal integrity, and mechanical reliability as designers integrate optics, audio systems, processing hardware, and motion control electronics.



Did You Know?

A humanoid robotic head can integrate dozens of sensors and multiple compute modules within a compact enclosure that must support continuous motion and high-speed data exchange.
This level of integration places unique demands on connector size, signal integrity, and mechanical reliability under dynamic conditions.

Typical head architecture includes the following subsystems:

- **Camera & LiDAR modules** — **enabling real-time perception and environmental awareness**
- **Microphones and speakers** — **supporting voice interaction and audio feedback**
- **Indicator lights or displays** — **communicating system status and user interaction**
- **Facial-movement mechanisms** — **controlling servomotors and actuators for expressions**

ENGINEERING REALITY

Maintaining stable electrical connections under continuous motion introduces combined mechanical stress, signal integrity challenges, & environmental variability not present in static systems.

Design Challenges:
Humanoid Head & Vision Systems

Designing connectivity inside humanoid robotic heads introduces a set of constraints that go beyond traditional embedded systems. Connector selection directly **impacts signal integrity, routing efficiency, and long-term reliability in these systems.**

1. High-speed signal integrity

Vision sensors & displays generate high-bandwidth data streams that must be maintained across short, densely routed interconnects between sensors, processing electronics, & control boards.

2. Compact, high-density layouts

Limited internal space drives tight PCB stacking and the use of miniature connectors without sacrificing electrical or mechanical performance.

3. Secure mating & shielding

Continuous motion and vibration place mechanical stress on connectors requiring robust retention and effective EMI shielding.

4. Reliability under real-world conditions

Systems must maintain performance under motion, thermal variation, shock, and vibration across extended operation.

Connector Solutions for
Humanoid Head & Vision Systems

Connector strategies in humanoid robotic head assemblies vary depending on **system function, data requirements, and environmental conditions.**

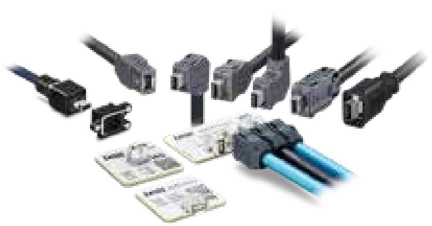
Most internal connections can be addressed using standard interconnect approaches designed for compact layouts and motion. However, certain subsystems, particularly vision and sensing, **introduce higher data rates & stricter signal integrity requirements.** In parallel, wiring architecture plays a **critical role in managing routing complexity & mechanical reliability within compact, moving assemblies.**

The following sections outline key elements of the interconnect strategy:

- **System-level connectivity approaches used throughout the architecture**
- **Performance-critical solutions required for high-speed data transmission**
- **Wiring architectures used to manage routing, flexibility, and integration complexity**

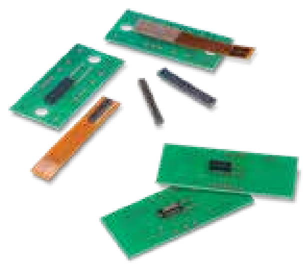
System-Level Connectivity

These connectors support the majority of internal system connections, including board-level integration, flexible routing, and subsystem communication.
At the system level, connector selection is primarily driven by **space constraints, routing complexity, and mechanical reliability under motion,** rather than maximum data rate.



ix Industrial™ Series

Rugged miniature Ethernet connector supporting **up to 10 Gb/s data transmission** in compact robotic assemblies. The robust metal shell and secure locking interface help maintain stable communication links in motion-intensive environments.



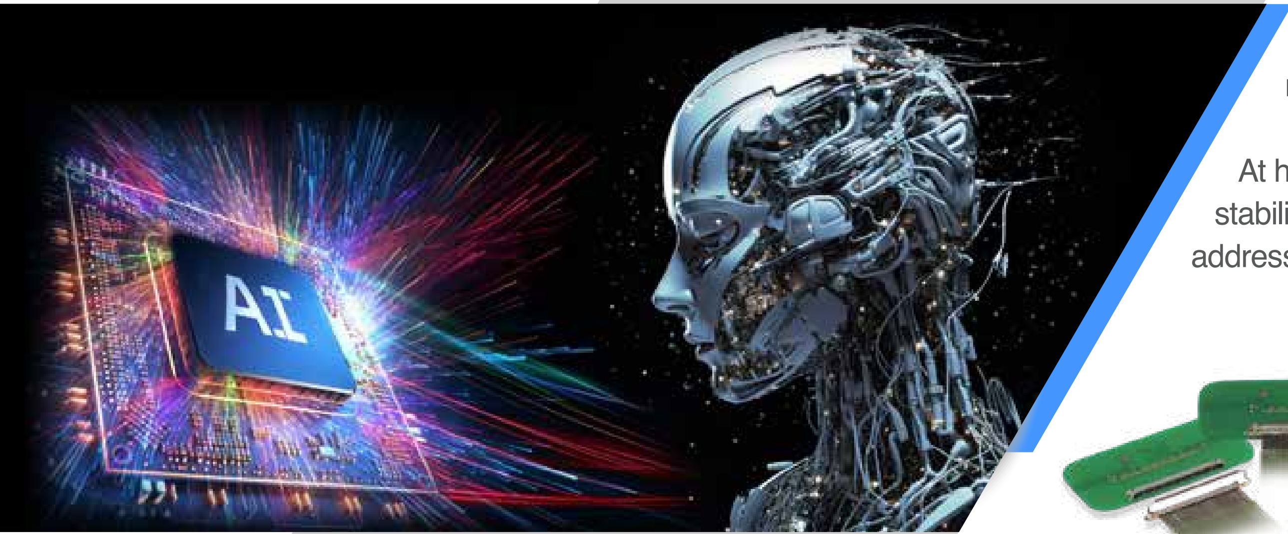
DF40 Series

Compact board-to-board connectors designed for **dense PCB stacking and high-speed signal transmission.** Multiple stacking heights and pin count options support flexible board-level integration in space-constrained robotic electronics.

FH34 Series

Low-profile **FPC/FFC connectors** enabling flexible, high-density wiring between sensors, displays, and control electronics. The compact design supports routing flexibility in tightly integrated assemblies.

Performance Critical Connectivity



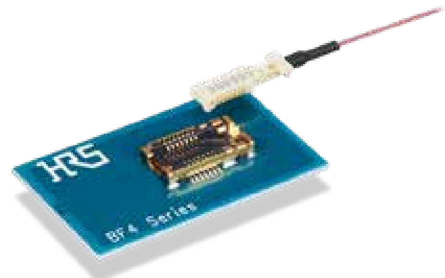
In contrast, vision systems and high-speed data paths **introduce constraints that extend beyond standard electrical interconnect performance.**

As perception capabilities expand—combining cameras, LiDAR, and AI processing—**the volume & speed of data moving through these systems increases significantly.**

At higher data rates, signal integrity, EMI, and connector stability under motion become limiting factors that must be addressed through **specialized interconnect solutions.**

DF81 Series

Micro-coaxial board-to-board connectors designed for high-speed signal transmission from cameras and sensor modules, with shielding structures that help maintain signal integrity in dense layouts.



BF4M Series

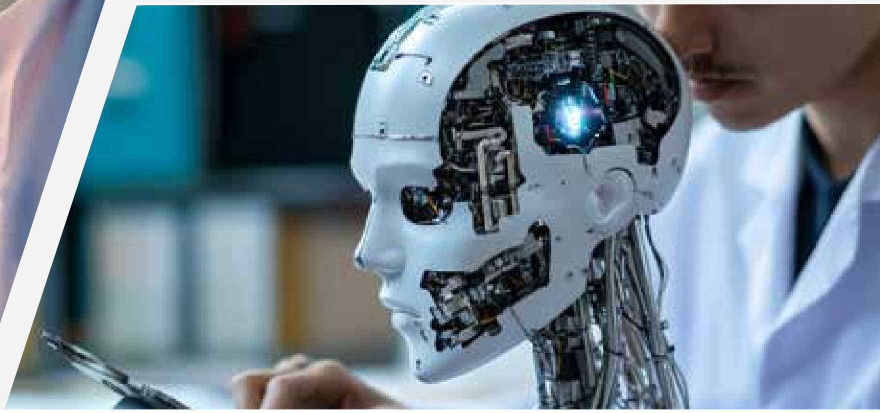
Optical interconnect solutions are used where electrical noise or bandwidth limitations become critical. Optical transmission provides immunity to EMI and supports stable high-speed communication.

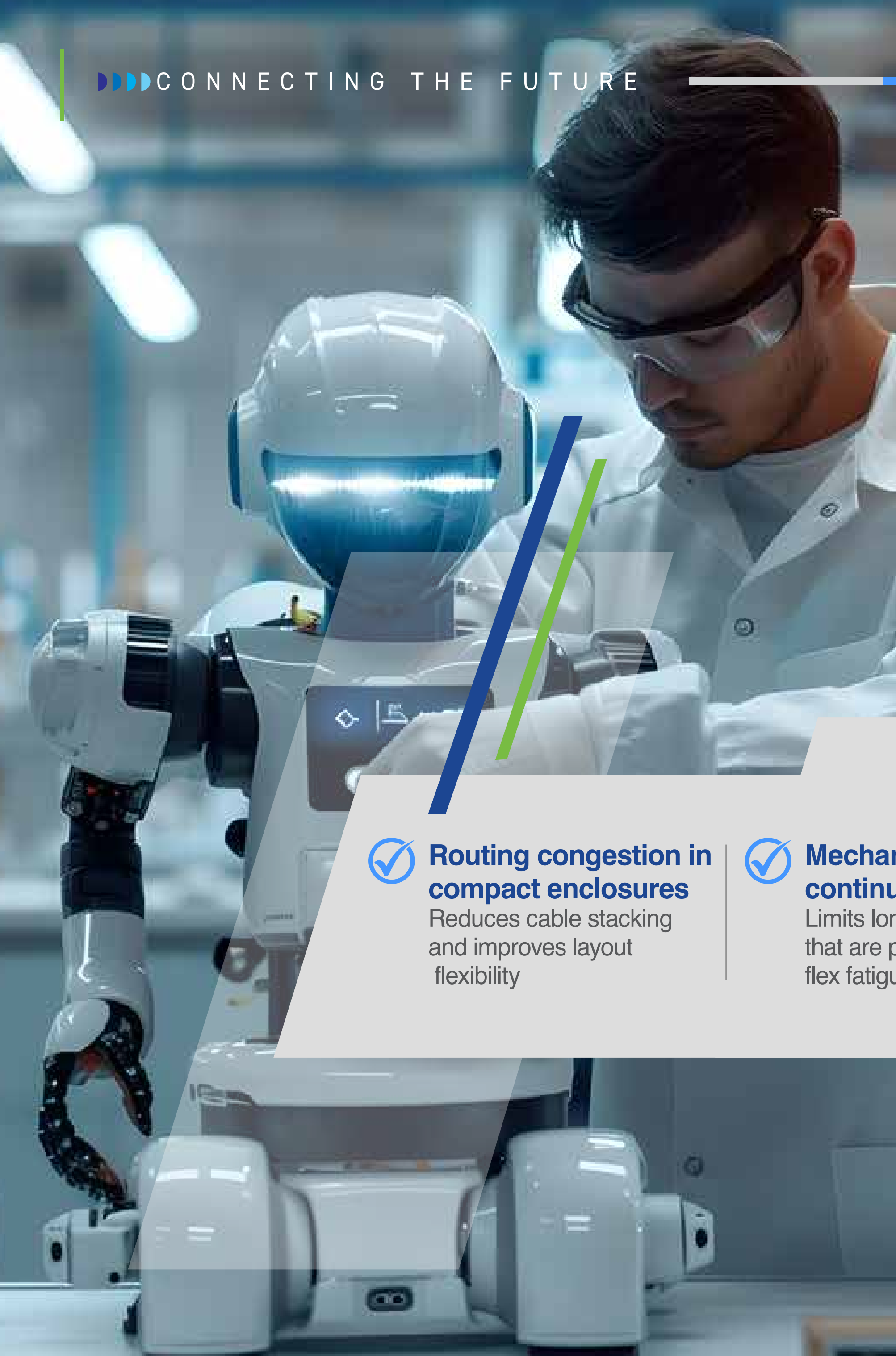
Wiring Architecture: Managing Complexity in Robotic Head Assemblies

Inside humanoid robotic heads, wiring does not scale linearly with system complexity.

As vision systems, sensors, and actuators are added, traditional point-to-point cabling increases routing congestion, weight, and mechanical stress within **compact, moving structures.**

To address these challenges, designers implement branch wiring, **where power and signals are routed** through primary harnesses with localized connection points near sensors and subsystems.





Why It Matters in Humanoid Head Design

In motion-intensive assemblies, wiring directly affects system reliability, not just packaging efficiency.

Branch architectures help address several key design constraints:

- **Routing congestion in compact enclosures**
  Reduces cable stacking and improves layout flexibility
- **Mechanical strain from continuous motion**
  Limits long cable runs that are prone to flex fatigue
- **Weight distribution in moving structures**
  Minimizes unnecessary cable mass within the head assembly
- **Assembly & service complexity**
  Simplifies installation and reduces rework during integration

Branch adapters support more modular system design. Sensors, cameras, and other head components can be connected or replaced without redesigning the entire harness, allowing connections to be made at nearby branch points instead of routing new cables back to the main controller. **This enables more efficient system iteration as designs evolve.**

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Designing Reliable Humanoid Robotic Systems

CONNECTING THE FUTURE

As humanoid systems move toward real-world deployment, connectivity decisions become increasingly difficult to correct later in the design process. Connector selection influences not only **signal performance, but also mechanical reliability, routing feasibility, & long-term serviceability.** In compact, motion-intensive assemblies, these factors are tightly coupled—small design tradeoffs can introduce system-level constraints that are difficult to resolve once architectures are established. **Designing connectivity early, alongside system architecture,** helps prevent avoidable redesign cycles, integration challenges, and reliability issues as systems scale.

Continue Exploring Humanoid Robotics

- Watch the Webinar
- Connector Selector Guide
- Humanoid Robotics eBook Series View Series
- Contact Us

SOURCES: MarketsandMarkets, Humanoid Robot Market – Global Forecast to 2030 — https://www.marketsandmarkets.com/Market-Reports/humanoid-robot-market-99567653.html
Research and Markets, Global Humanoid Robots Market Report, March 2026 — https://www.researchandmarkets.com/reports/6197133/global-humanoid-robots-market-report-2026