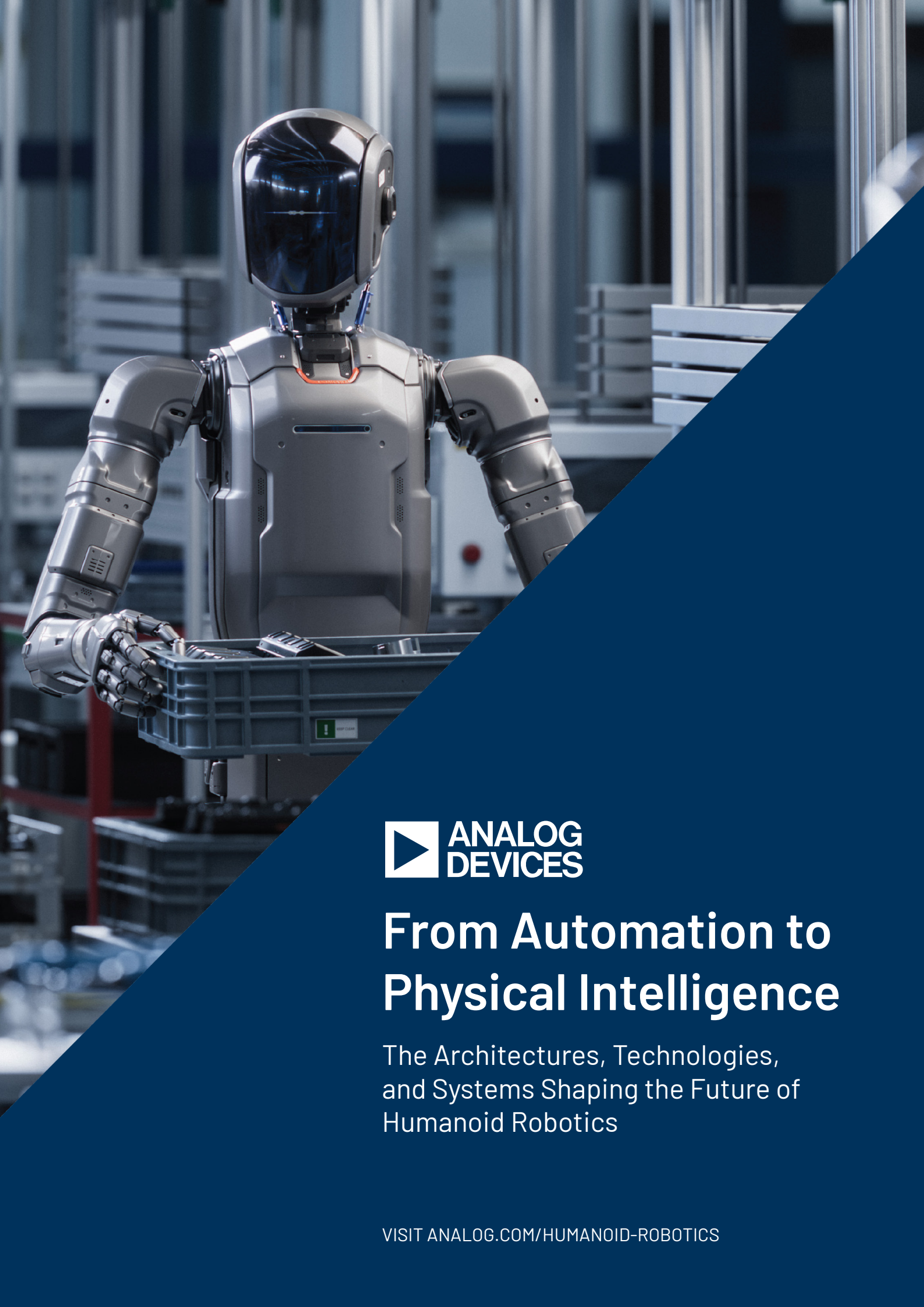




From Automation to Physical Intelligence

The Architectures, Technologies,
and Systems Shaping the Future of
Humanoid Robotics

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FOREWORD

BY DARA O'SULLIVAN, DIRECTOR OF SYSTEM APPLICATIONS, SMART MACHINES & ROBOTICS, INDUSTRIAL AUTOMATION, ANALOG DEVICES, INC.

For decades, robotics has progressed through incremental advances in sensing, control, and automation. Today's robotics industry is different. We are witnessing the convergence of breakthrough technologies across sensing, connectivity, edge computing, motion control, power management, and artificial intelligence. Together, these innovations are creating a new generation of machines capable of perceiving, reasoning, and acting in the physical world with unprecedented adaptability.

What makes this moment unique is not any single technology. It is the way these technologies are reinforcing one another. Richer sensing creates more data. More data demands distributed intelligence. Distributed intelligence enables more capable motion. More capable motion requires greater awareness, connectivity, safety, and energy efficiency. The result is a compounding innovation cycle that is accelerating the evolution of robotics.

This eBook explores the foundational technologies and system-level design considerations enabling this transformation. From physical intelligence and distributed compute architectures to multimodal perception, dexterous manipulation, motion control, power intelligence, and functional safety, each chapter examines a critical piece of the modern robotics stack.

Ultimately, the future of robotics will be defined not by individual components, but by how seamlessly they work together. That future is already taking shape, and its foundation is physical intelligence.

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THE NEW INDUSTRIAL ROBOTICS ERA: WHY INNOVATION IS COMPOUNDING

Imagine a robot stepping out of a safety cage, not to perform a single preprogrammed motion, but to work alongside people. It navigates a cluttered aisle. It pauses when a pallet shifts unexpectedly. It picks up a part it's never seen before, adjusts grip based on force feedback, and completes the task without a line stop.

Until recently, that scenario belonged to lab demos and conference highlight reels. In industry, robotics was built on predictability: structured environments, deterministic routines, and long integration cycles.

Now the ground is moving. Robotics is entering a supercycle where innovation compounds. What once took decades to reach mainstream adoption now emerges in a matter of years, sometimes even months. And the earliest impact is not in consumer gadgets, it's on factory floors, in warehouses, and across logistics networks where milliseconds, uptime, and safety are non-negotiable.



Robotics is entering a supercycle where innovation compounds. What once took decades to reach mainstream adoption now emerges in a matter of years, sometimes even months.

THE SHIFT: FROM LINEAR PROGRESS TO EXPONENTIAL CONVERGENCE

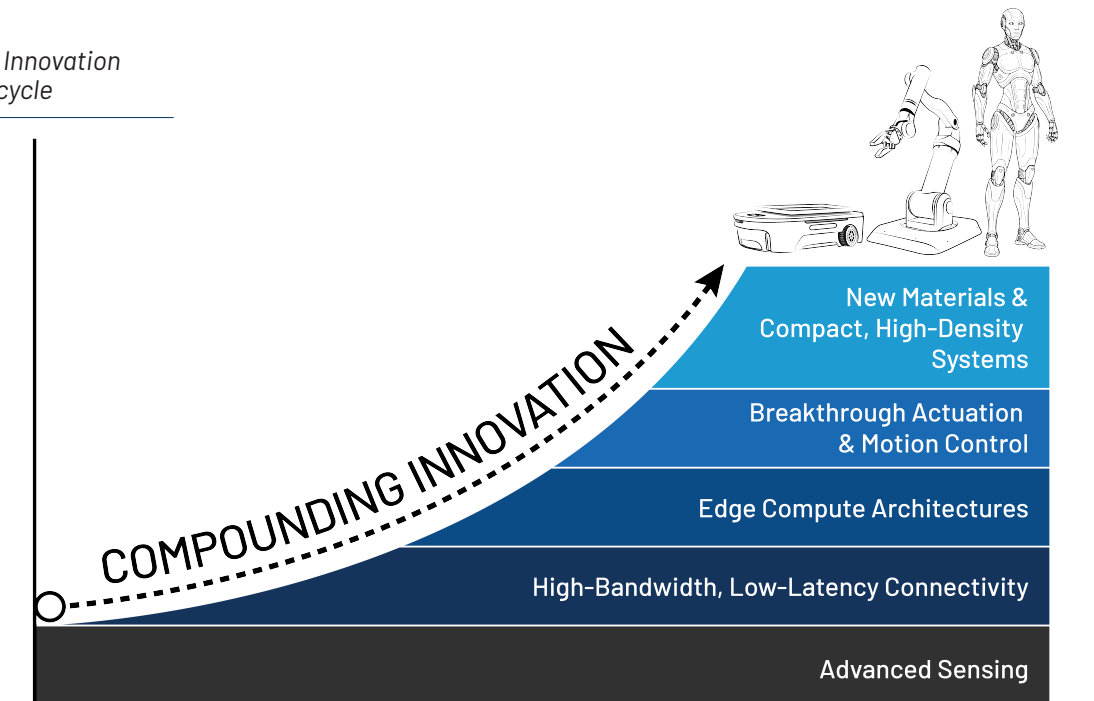
Robotics feels like it's suddenly leaping forward because we're witnessing the convergence of historically separate innovation tracks:

- **Advanced sensing** gives robots nuanced, contact-aware manipulation
- **High-bandwidth, low-latency** connectivity enables synchronized, real-time robotic systems
- **Edge compute architectures** eliminate cloud latency for real-time robot control
- **Breakthrough actuation and motion control** enable safe, adaptive, and dexterous robot movement
- **New materials and compact, high-density systems** enable lightweight, power-efficient robotic designs

Each of these technologies is advancing on its own; but critically, each also enables the others to advance faster. This creates a closed loop:

1. Better sensors produce richer, more frequent data
2. Richer data demands edge compute, not cloud latency
3. Edge compute enables more complex, adaptive motion
4. Adaptive motion requires better actuators and materials
5. Those actuators generate new, higher-fidelity feedback

Figure 1: Compounding Innovation Driving Robotics Supercycle



This loop is tightening ... and accelerating. Every breakthrough amplifies the next one. That's the signature of a compounding innovation cycle and explains why the gap between what robots *could* do and what they *can* do today is shrinking at an unprecedented rate.

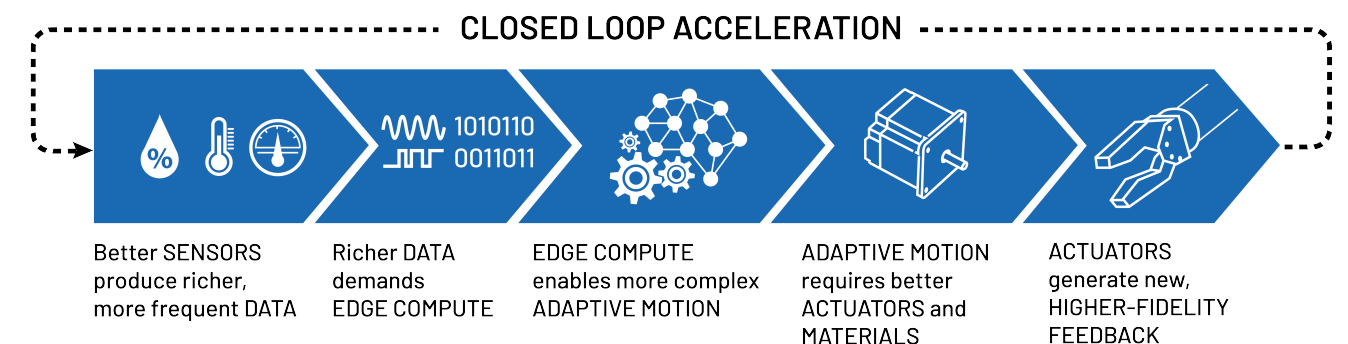
WHY INDUSTRIAL ROBOTICS IS THE FRONT LINE OF THIS SHIFT

Consumer robotics (lawn mowers, vacuum cleaners, educational robots) gets the headlines. Industrial robotics gets the breakthroughs first. The reason is simple: industrial environments demand determinism, resilience, and speed.

They operate under constraints that consumer robotics rarely face. Safety requirements are unforgiving. Downtime can cost millions. Environments are dynamic, cluttered, and unpredictable. Humans and machines must work side by side every day.

To thrive under these conditions, robots must sense, decide, and act within milliseconds, directly at the edge. A robot navigating a factory floor or manipulating delicate components cannot wait 200+ milliseconds for a cloud round-trip. The sensing-to-decision-to-actuation loop must run locally, with deterministic timing. This requirement is driving a renaissance in real-time edge intelligence, as well as transforming what robots can do.

Figure 2: Closed Loop Acceleration for Technology Advancement





This combination of real-time sensing, local decision-making, and adaptive motion is what we call physical intelligence.

Industrial robotics is no longer just automation. It's becoming **adaptive autonomy**: systems that reconfigure on the fly, respond to changing conditions, collaborate with humans, and coordinate complex tasks across distributed compute nodes.

Traditional factories were designed around predictability. Production lines were fixed. Workflows were static. Robot behavior was preprogrammed, validated once, and left unchanged for years. Efficiency came from minimizing variation, not responding to it.

That model is breaking down. Modern factories are being forced to operate in environments defined by variability, shorter product lifecycles, and constant change. As a result, they are shifting toward:

- **On-the-fly reconfiguration**, where lines and workflows adapt without lengthy shutdowns
- **Dynamic logistics**, with materials, inventory, and robots continuously rerouting in response to demand
- **Continuous inspection**, embedded directly into production rather than isolated at the end of the line
- **Human-robot collaboration**, where machines work safely alongside people instead of behind cages
- **Rapid product changeover**, measured in hours or minutes rather than weeks

These capabilities demand a fundamentally different kind of robotics: systems that tightly integrate sensing, perception, and adaptive behavior, all driven by real-time, deterministic intelligence at the edge. The result is a shift in how factories behave: less like rigid, sequential machines, and more like **dynamic ecosystems** that are responsive, resilient, and capable of adapting as conditions change.

WHY THIS MOMENT MATTERS

Robots are finally operating in the real world, not just inside structured cells. They move through aisles, collaborate with humans, navigate clutter, and manipulate objects that weren't preplanned for them. Dexterity and mobility are improving simultaneously. The last era of robotics made robots precise. This era is making them adaptive. These requirements apply across advanced industrial robotics, but humanoids bring them together at an unprecedented level of system complexity. The question is no longer whether industrial robots will become adaptive and general-purpose, but how quickly organizations will learn to design, deploy, and trust them.

When richer sensing converges with faster, deterministic edge intelligence, adaptive motion control, advanced connectivity and energy-aware operation, something fundamental changes. Robots stop being specialized machines and start becoming smart, resilient general-purpose workers in industrial environments. This combination of real-time sensing, local decision-making, and adaptive motion is what we call **physical intelligence**.



REAL-TIME ROBOTICS: THE RISE OF PHYSICAL INTELLIGENCE

What is physical intelligence? This chapter focuses on defining what physical intelligence is, why it's fundamentally different from traditional automation or cloud AI, and what considerations matter when intelligence leaves the abstract world of data and enters the physical world of motion, force, and interaction.

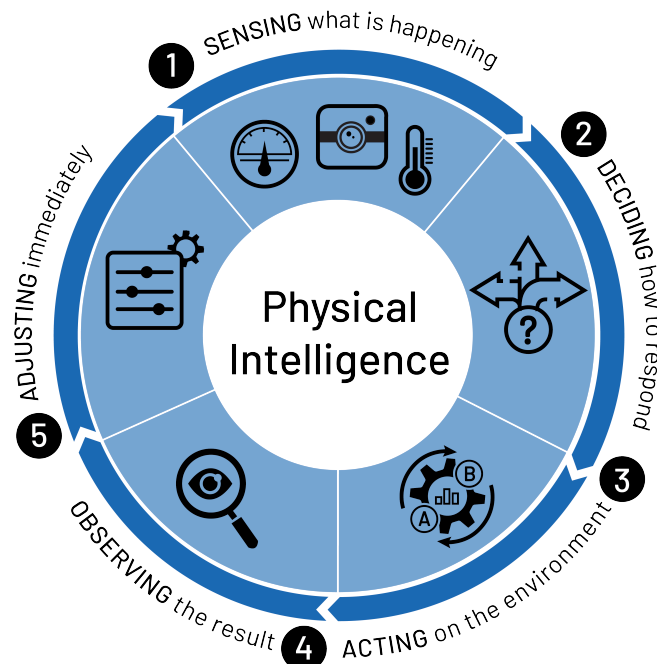
With robotics entering a supercycle where sensing, deterministic edge compute, connectivity, and adaptive motion reinforce one another, pushing robots beyond rigid automation, the result is a new class of systems that don't just execute preprogrammed steps but operate with **physical intelligence**.

Physical intelligence emerges from a closed loop:

- Sensing what is happening
- Deciding how to respond
- Acting on the environment
- Observing the result
- Adjusting immediately

In the physical world, this loop is not optional. It is the minimum requirement for stability, safety, and useful work. This loop runs continuously while the robot is moving, manipulating, or interacting. Unlike software workflows or cloud inference pipelines, there are no natural pauses. In the physical world, time never stops ticking, and intelligence must move in lockstep with it.

Figure 3: Physical Intelligence Closed Loop



Physical intelligence emerges from a closed loop.

When this loop is well-coordinated, robots move smoothly, handle uncertainty, and collaborate naturally with people. When it breaks down, the failure is not abstract; it's visible as hesitation, oscillation, dropped parts, hard stops, or safety incidents. In software, a delayed response might mean a slow page load. In robotics, it means instability, damaged equipment, or unacceptable risk.

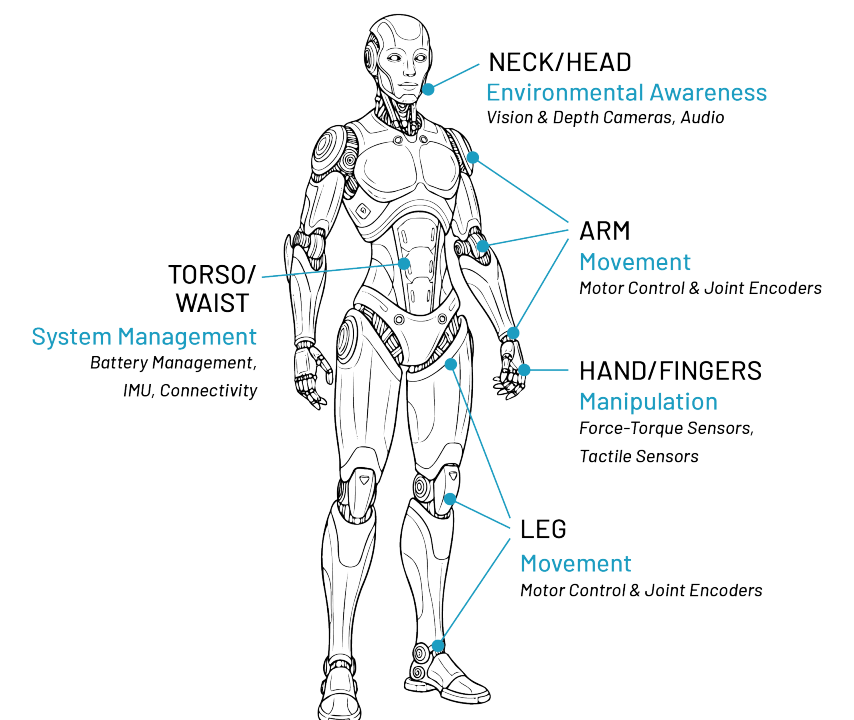
This is why physical intelligence is fundamentally a systems problem. It depends not only on models and algorithms, but on how perception, decision making, and control are orchestrated as one coherent time-synchronized system.

FROM PERCEPTION TO ACTION

Modern robots are rich in perception. Vision and depth cameras map environments. Force-torque sensors measure interaction. Inertial measurement units (IMUs), joint encoders, and tactile sensors provide continuous feedback about the robot's own body. Together, these systems generate a continuous stream of state ... not snapshots, but an evolving understanding of both the environment and the machine itself.

However, perception alone is not intelligence. Intelligence emerges only when perception is translated into controlled action in a way that remains stable under real-world conditions. That translation is what enables capabilities like contact-aware manipulation, safe proximity behavior around humans, continuous inspection during handling, and navigation through dynamically changing environments. They are ongoing behaviors maintained over time, under uncertainty, while the robot and its surroundings are both in motion. This shifts next-generation robotics away from a single 'brain' making occasional decisions and toward architectures that can sustain continuous sensing, control, and response.

Figure 4: Modern Robots Are Rich in Perception





Awareness is not a feature layered on top of automation. It is a continuously maintained condition, the prerequisite for autonomy in the physical world.

AWARENESS IS THE REAL FRONTIER

The promise of physical intelligence is not simply better robots; it's more adaptable systems.

Physically intelligent robots can:

- Reconfigure workflows without long shutdowns
- Handle part and process variability without reprogramming
- Inspect and adjust during production instead of after failures
- Collaborate directly with people in shared spaces
- Move through dynamic environments without rigid constraints

All these capabilities depend on awareness: the ability to remain continuously attuned to what is happening and to respond appropriately as conditions change. Awareness is not a feature layered on top of automation. It is a continuously maintained condition, the prerequisite for autonomy in the physical world.

WHY PHYSICAL INTELLIGENCE STARTS AT THE EDGE

Physical intelligence is embodied: it is shaped by, and inseparable from, the physical body that senses, moves, and interacts with the world. It is embodied in the robot's physical structure and dynamics. Rather than existing solely as abstract computation, it emerges through continuous feedback between sensors, actuators, and the environment. Because of this, physical intelligence must live close to the robot's body, near sensors, actuators, and the dynamics they govern. This doesn't mean all intelligence is local, or that centralized compute has no role. Higher-level reasoning, planning, learning, and coordination benefit from broader context and longer horizons. But moment-to-moment awareness (the intelligence that keeps a robot stable, responsive, and safe) must be tightly coupled to the machine itself.

As a result, intelligent robots increasingly resemble biological systems: intent and cognition at higher levels, with rapid reflexes and coordination distributed throughout the body, all operating as one synchronized system. That architectural shift from centralized automation to embodied physical intelligence is what enables robots to operate reliably in open-ended, real-world conditions.

WHAT COMES NEXT

We often talk as if AI is driving robotics. Increasingly, robotics is reshaping AI, forcing it to become more grounded, more energy-aware, more distributed, and more accountable to physics. Physical intelligence demands more than accuracy or scale; it demands systems designed around motion, interaction, and time.

If we want AI that can act in the real world, we need to start designing it for the real world. It's time to rethink intelligence from the ground up, starting with the machines that move, sense, and interact.



INSIDE THE DISTRIBUTED BRAIN: WHERE ROBOTIC INTELLIGENCE LIVES

As robots move into open environments where they interact with people, determining where sensing, decision making, and control run becomes critical for stability, safety, responsiveness, and trust. Humanoids face a fundamental whole-body control problem: every joint, sensor, and actuator must coordinate to maintain balance and purposeful motion. If coordination breaks down, the robot falls.

The previous chapter defined physical intelligence and why intelligence changes when it leaves the abstract world of data and enters the physical world of motion, force, and interaction. This chapter explores **where robotic intelligence actually lives** and how responsibilities are split across central compute, edge systems, and local control and why these architectural choices matter.

WHY REAL TIME MATTERS: THE WORLD DOESN'T WAIT

Modern robots behave as distributed systems, where perception, state estimation, policy, planning, and control are continuously coordinated across the body to produce stable, real-time behavior.

In physical systems, latency is a stability problem: the difference between a stable step and a fall, a controlled grasp and a dropped part, a smooth stop and a safety incident. For behaviors like balance correction, collision reflexes, slip detection, and contact-aware motion, tens of milliseconds matter. Jitter, or unpredictable timing, can be worse than a fixed delay.

This leads to a first principle of physical intelligence: if the robot moves, the intelligence governing that motion can be centralized, but the control of motion must happen locally and on a predictable and deterministic schedule.

SPEED ALONE IS NOT ENOUGH: DETERMINISM IS THE FOUNDATION

Robots need **deterministic latency**, not just low latency. Physical intelligence operates as a continuous loop: sensing, deciding, acting, observing, and adjusting. That loop must execute on time, every time. When timing slips, the loop destabilizes, causing oscillation, hesitation, collisions, dropped objects, or hard stops.

Deterministic operation is the substrate everything else depends on. Without it, safety mechanisms fail and human collaboration becomes impossible. With it, robots can move smoothly and remain stable in the face of uncertainty.



Humanoids face a fundamental whole-body control problem. If coordination breaks down, the robot falls.

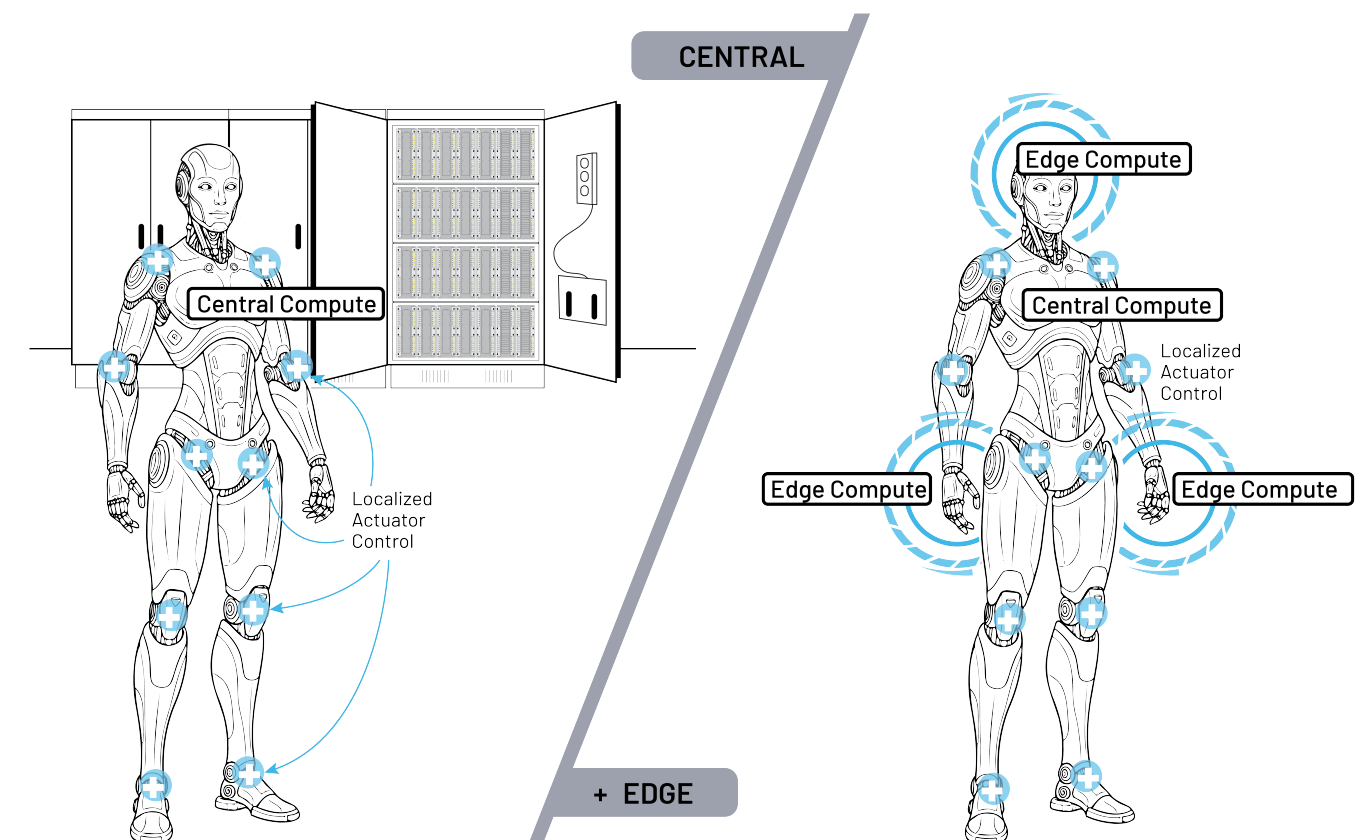
WHOLE-BODY INTELLIGENCE: CENTRAL POLICY, DISTRIBUTED EXECUTION

Humanoids intensify the architectural tension between centralization and distribution. The robot's entire body is coupled, benefiting from a central "brain" that can reason over the whole-body state and coordinate motion as one coherent system. This drives designs toward **highly centralized intelligence**.

Central compute handles global state estimation, whole-body coordination, learned policy inference, task-level reasoning, intent, and long-horizon planning. These functions benefit from global context and a unified view of the robot.

However, if every tactile event, motor current spike, joint encoder tick, **inertial measurement unit (IMU)** update, and camera stream ships to that central brain in raw form, the robot quickly becomes a bandwidth and scheduling nightmare. Edge nodes must perform data prioritization and filtering, deciding what to send, what not to send, and what is urgent. The pattern is **centralized coordination, distributed execution, and embedded reflexes**, all synchronized in time.

Figure 5: The Distributed Brain of Modern Industrial Systems



THREE LAYERS OF INTELLIGENCE (AND WHY EACH EXISTS)

- **Central Intelligence: Intent, Policy, and Whole-Body Coordination**

This layer knows what the robot is trying to do. Central intelligence handles global coordination, but rarely runs the fastest reflexes. In humanoids, this matters because coordination is holistic: controlling an ankle, shoulder, and torso is not separable when balance is at stake. Modern systems increasingly run AI-based policy learning here for complex, high-dimensional control.

- **Edge Intelligence: Real-Time Control, Safety, and Data Reduction**

This layer maintains system responsiveness under real-world timing constraints. It stabilizes motion, enforces safe torque and force limits, manages local sensor fusion, and reduces high-rate signals into decision-critical information. Instead of streaming everything upstream, the system filters and aggregates locally.

- **Embedded Intelligence: Reflexes at the Actuator and Contact Point**

The fastest control loops live here. Every actuator has its own local motor controller, responding to events that unfold too quickly to tolerate additional latency. This reflex layer includes motor current regulation, joint position control, safety enforcement, and the detection of microscale contact events like tactile spikes and slip events. These loops don't call the main computer: the safest response never leaves the joint, hand, or end effector.

A SIMPLE EXAMPLE: CARRYING AN OPEN CONTAINER

Consider a humanoid carrying a partially filled open container down a busy industrial aisle. What appears simple spans multiple time domains.

- **Embedded Control and Reflexes (sub-5ms class):** joint stabilization, local torque loops and limits, grip micro-adjustments, slip detection, and fast disturbance rejection. These loops must be local at the actuator/hand.
- **Whole-Body Control (5ms to 20ms class):** whole-body planning, perception and motion sensor fusion, contact state estimation, joint coordination, obstacle proximity reactions, and safety enforcement.
- **Learned Policy (≥50ms):** route selection, human motion prediction, task intent (“keep container upright while making progress”), and policy-level decisions.

Too much centralization produces slow, hesitant behavior. Too much decentralization produces fast reactions without coherent intent. Physical intelligence lives in the balance: global intent and local reflex, operating as one synchronized system.

WHY THIS ARCHITECTURE MATTERS

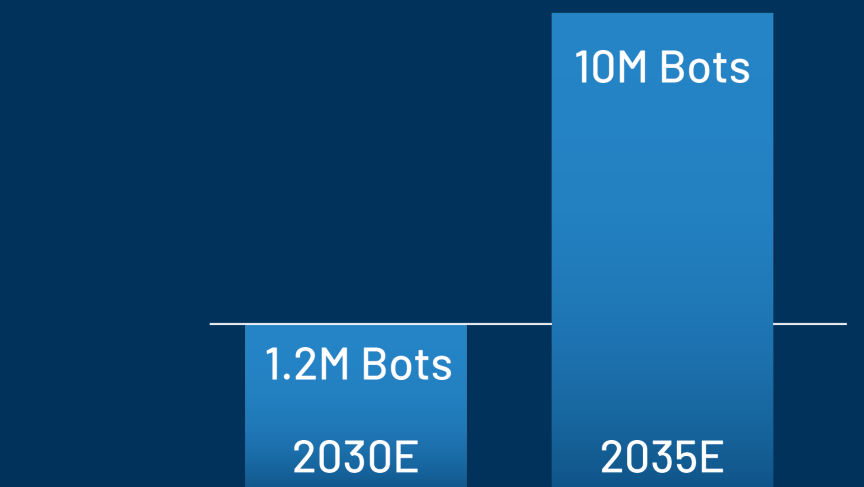
The distributed brain is not just a performance optimization. It is the foundation for:

- Natural, stable motion
- Safe collaboration with people
- Dexterous manipulation and contact awareness
- Real-world operation under uncertainty
- Resilient, reconfigurable industrial workflows

This is how robots move beyond automation and toward physical intelligence by putting intelligence where timing, interaction, and safety demand it.



Physical intelligence
lives in the balance:
global intent and local
reflex, operating as one
synchronized system.



HUMANOID SHIPMENT FORECAST

Source: “Physical AI, part 2: Humanoid robots” BofA Global Research Estimates
<https://institute.bankofamerica.com/transformation/physical-ai-part-2.html>
March 7, 2025



MULTIMODAL PERCEPTION & CONNECTIVITY: THE NERVOUS SYSTEM OF HUMANOID ROBOTICS



Humans don't rely on a single sense to understand their environment.

A humanoid robot doesn't experience the world through a single sensor or decision point. It perceives, interprets, and reacts through a continuous flow of information moving across its body between sensors, compute nodes, and actuators at precisely the right time.

This chapter focuses on how robots perceive the world through multiple modalities and how high-performance connectivity synchronizes these data streams into a unified, time-coherent understanding of the environment. This is the next foundational layer after we've explored how physical intelligence emerges from real-time sensing, distributed compute, and deterministic control in previous chapters.

Modern humanoid robots are not isolated machines; they are networked, multimodal intelligence platforms whose capabilities depend on the fusion of sensing, actuation, and high-performance communication. This convergence is redefining what robots can safely and reliably do in human environments.

WHY MULTIMODAL PERCEPTION IS NON-NEGOTIABLE

Humans don't rely on a single sense to understand their environment. We continuously integrate vision, sound, touch, balance, and proprioception to maintain context while we move. Robots operating in real-world, human-shared environments must do the same. No single sensor modality is sufficient for the messiness of reality. Modern humanoids increasingly fuse:

- Vision for spatial understanding and semantic context
- Depth sensing for geometry and distance
- Audio for intent, anomalies, and out-of-view awareness
- Tactile sensing for manipulation and contact awareness
- Inertial measurement units (IMUs) and joint encoders for balance, orientation, and proprioception
- Force and torque sensing for safe interaction and loading perception

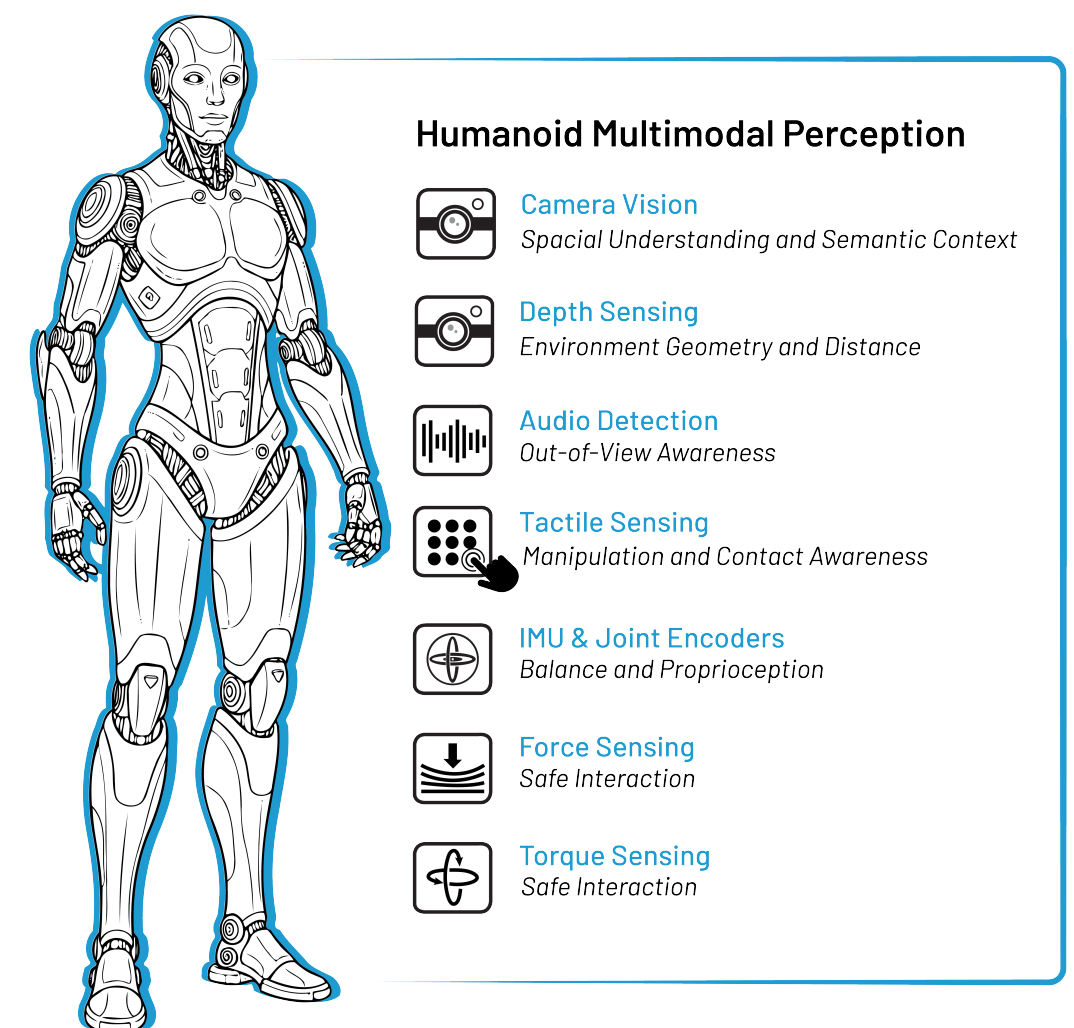
Each modality compensates for the limitations of the others. Together, they enable robust perception under motion, glare, occlusion, clutter, noise, and uncertainty. A humanoid cannot act intelligently until it can perceive intelligently, continuously, and in context.

CONNECTIVITY: THE ROBOT'S NERVOUS SYSTEM

Perception generates data. Connectivity moves and synchronizes that data. For humanoids, connectivity is the nervous system that synchronizes the entire body. Rather than monolithic machines, humanoid architectures are increasingly built as distributed, interconnected networks. Camera zones, sensing zones, and actuation zones all connect through a hierarchy of communication links, ranging from modest data rates at the edge to high-speed backbone connections.

Vision sensors in the head, tactile sensors in the fingertips, IMUs in the torso, force sensors in joints, actuators across limbs, and distributed processors must all communicate in lockstep. Even millisecond-scale delays or jitter can mean instability, missed contacts, or unsafe behavior. If perception is unsynchronized, the robot doesn't just slow down; it becomes unsafe.

Figure 6: Humanoid Multimodal Perception Overview



THE CONNECTIVITY BACKBONE

The internal network of a humanoid must support:

- Sub-millisecond coordination
- Deterministic timing
- High-bandwidth sensor fusion
- Safety-critical communication
- Power and data delivery through constrained form factors

This drives adoption of technologies such as:

- Time-sensitive networking (TSN) Ethernet
- High-speed camera and sensor links
- Low-latency actuator buses
- Distributed sensing networks
- Combined power and data architectures

Without this backbone, edge intelligence is starved of synchronized context. If the network is slow, the robot is slow. If it's unreliable, the robot is unsafe. As perception stacks grow richer, connectivity demands scale exponentially. Technologies like Gigabit Multimedia Serial Link (GMSL™), TSN Ethernet, and Ethernet to the Edge Bus (ADI E²B®) are combining to ensure reliable communication across the entire humanoid nervous system.

FROM DATA STREAMS TO UNIFIED AWARENESS

When multimodal perception and deterministic connectivity converge, robots gain something humans take for granted: a coherent sense of self and surroundings.

This unified awareness enables smooth stable locomotion, safer collaboration with people, adaptive manipulation, predictive motion planning, and consistent behavior in uncertainty. This is the difference between a robot that merely moves and one that understands.

Ultimately, multimodal perception and connectivity are not just engineering challenges; they are enablers of more human-like behavior. By distributing intelligence, prioritizing data intelligently, and designing connectivity as a layered nervous system, robots become more responsive, more capable, and more intuitive in how they interact with the world.

Figure 7: Humanoid Connectivity Overview

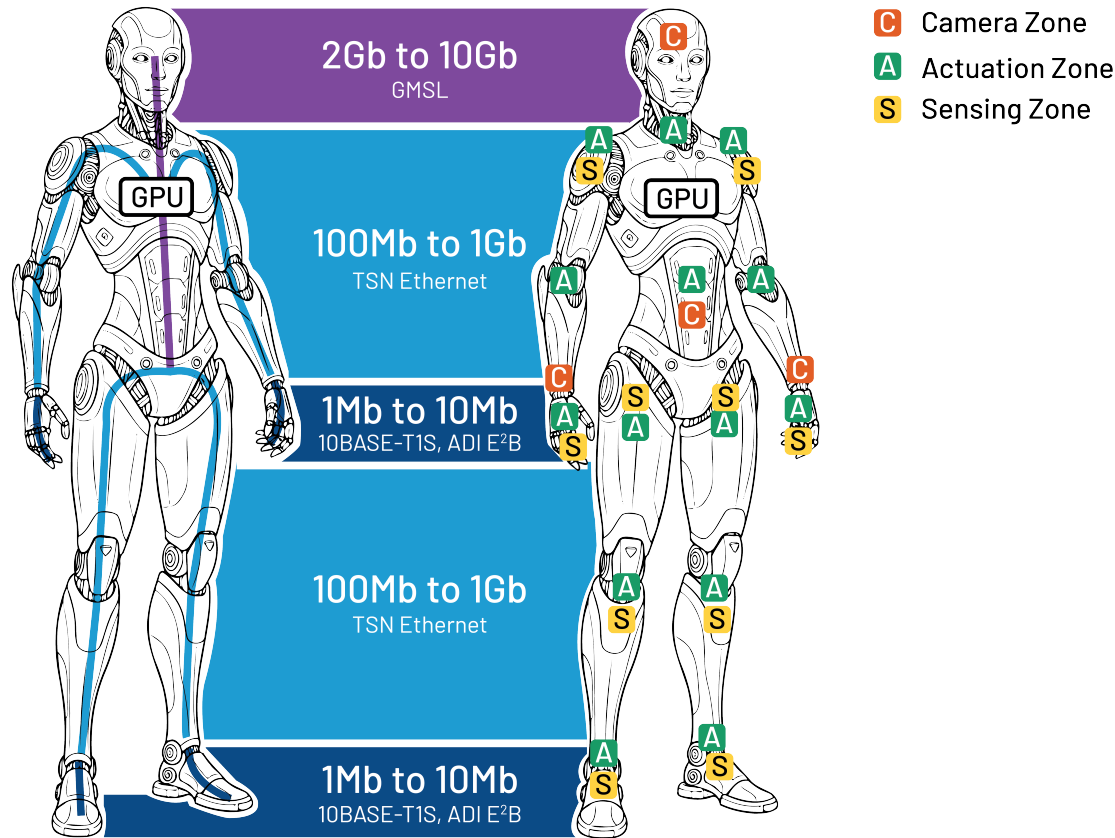


Table 1: Connectivity Technology Breakdown

Connectivity Technology	Speed*	Use
Gigabit Multimedia Serial Link (GMSL)	2Gb to 10Gb	For high-resolution, uncompressed video data, control signals, and power over long-distance coaxial or shielded twisted pair cables
TSN Ethernet ADIN3310 ADIN6310	100Mb to 1Gb	Provide deterministic connectivity (guaranteed packet transport with bounded latency) including lower resolution sensing and vision data (for example, hand camera)
RS-485	>10Mb	For edge connectivity that needs greater than 10Mb
Ethernet to the Edge Bus (ADI E²B)/T1S AD3300	1Mb to 10Mb	10BASE-T1S remote control protocol that enables Ethernet connectivity directly to edge nodes for joint actuation and tactile/force/inertial sensor data

* Illustrative timing classes; actual partitioning varies by robot architecture and control strategy

THE HUMANOID HAND: THE ULTIMATE EDGE COMPUTE CHALLENGE

If mobility is what allows a humanoid robot to move through the world, dexterity is what makes it matter. A humanoid robot walking through a factory is impressive; but walking is not the hard part. The real challenge lies in manipulation: picking up a tool, threading a cable, adjusting a valve, or placing a fragile object onto a conveyor. These tasks demand that robots generalize across a wide range of physical interactions while operating under tight constraints on sensing, control bandwidth, and latency.

Achieving dexterous manipulation pushes sensing, compute and control to the limits of what can be done at the edge, as humanoids reason about how to interact with objects:

- This is a handle: grasp laterally
- This surface is reflective: adjust depth strategy
- This object is deformable: reduce grip force

Humanoid hands are the densest edge-compute engineering challenge in the entire robot body where sensing, actuation, wiring, and micro-reflex control all converge under the tightest latency, power, thermal, and size constraints.

WHY THE HAND IS THE TOUGHEST DESIGN CHALLENGE

Humans modulate grip force without thinking. We sense slip before an object falls. We adjust contact pressure as surfaces change. We reposition objects mid-motion with tiny corrections that never rise to conscious attention.

Replicating even a subset of those capabilities in a humanoid requires more than clever mechanics. It demands breakthroughs across:

- High-density tactile sensing
- Precision motion control
- Compact actuation
- Fine motor coordination
- Efficient wiring
- Low-latency local compute
- Robust power management

All of this must be integrated into a form factor that must remain lightweight, durable, and safe around humans. This is why the hand is not just an end effector; it is a closed-loop control system embedded inside a highly constrained form factor, not a peripheral device awaiting instructions.

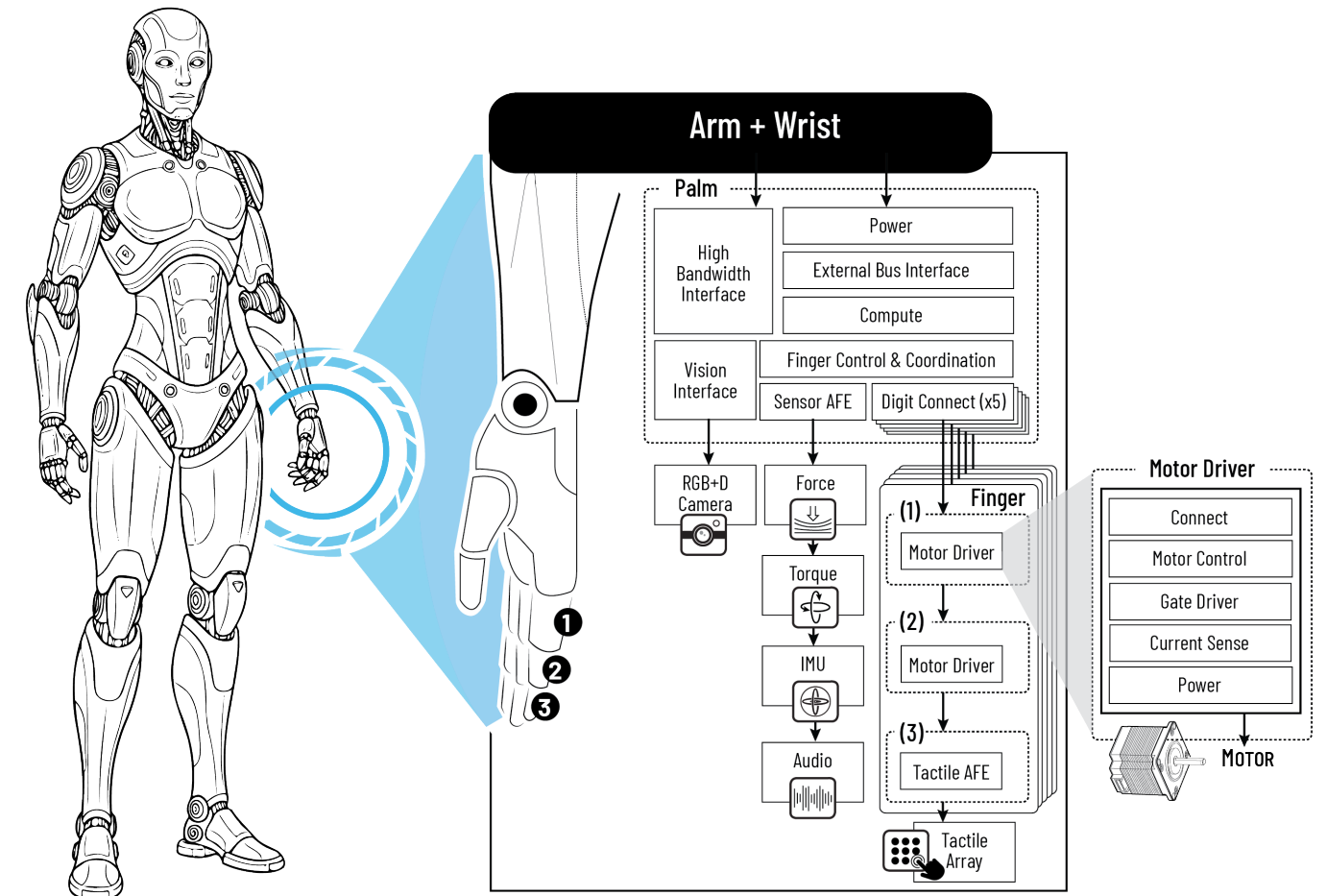


Figure 8: Humanoid Hand:
Multi-Sensor, Multi-Actuator
Platform for Fine Motor Control

MANIPULATION REQUIRES LAYERED PERCEPTION

Dexterous manipulation requires triangulating reality across multiple modalities, each contributing a different piece of awareness:

- **Vision:** What is the object? Where is it?
- **Depth:** What is its geometry and distance?
- **Tactile Sensing:** Is it slipping? Is the force correct?
- **Proprioception:** What is the state of the humanoid's joints and body?

A humanoid hand handling a soft package, a fragile component, or a reflective metal part must constantly reconcile these signals. Fusing these inputs means that a robot can adjust grip force, finger position, and motion trajectories in real time. This layered perception is what enables human-like dexterity.

DEPTH: GEOMETRY AT HUMAN SCALE

Time-of-flight (ToF) depth sensing is an essential complement to RGB vision. By fusing RGB data with depth information, humanoid robots achieve 3D perception. Positioning RGB+D camera technology on the wrist or within the palm allows the hand full field of vision to accomplish tasks efficiently.



Humanoid hands are the densest edge-compute engineering challenge in the entire robot body.

TACTILE: THE HAND'S "SKIN"

Taking contact geometry, pressure distribution, micro-slip signatures, surface friction, vibration, etc. into account, tactile sensing is the key to humanoid robots being able to tackle any task. How does it work? Let's look at the steps involved:

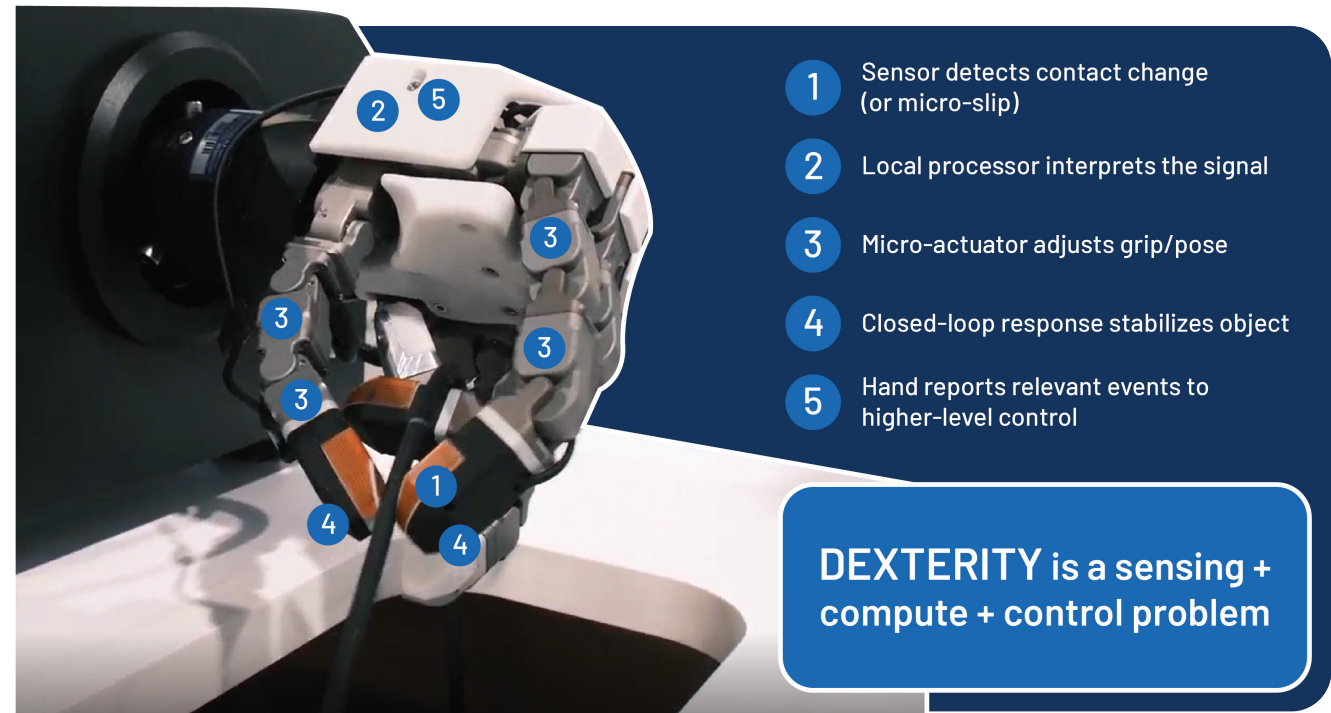
1. Sensor detects contact change (or micro-slip)
2. Local processor interprets the signal
3. Micro-actuator adjusts grip/pose
4. Closed-loop response stabilizes object
5. Hand reports relevant events to higher-level control

This is the hand's hidden truth: dexterity is a sensing + compute + control problem as much as it is a mechanical one. That's why the hand increasingly needs smart integration: tight co-design of sensing, signal chains, local compute, power delivery, and thermal management in a compact, ruggedized stack.

AUDIO: THE UNDERRATED SENSE

While vision and depth dominate discussions of robot perception, audio is often underestimated. Yet sound provides a dimension of awareness that vision cannot. Humanoid robots use audio sensing to detect mechanical anomalies through vibration and acoustic signatures. They can verify when a cable has been inserted correctly by recognizing the unmistakable "click" sound confirming it is locked in place. Where better to hear this signature than when located in the hand performing the task?

Figure 9: Tactile Loop for Dexterous Humanoid Hand Manipulation



INERTIAL SENSING: VERIFYING INTERACTION, NOT JUST MOTION

Vision and touch tell a humanoid what should be happening. Inertial sensing helps confirm what actually happens. High-bandwidth accelerometers embedded in the hand can detect micro-events (impacts, clicks, vibration signatures, or sudden changes in force) that are difficult to interpret from any single modality alone. For example, the mechanical "click" indicating a connector is fully seated may be audible, but it also produces a characteristic impulse detectable through precision inertial sensing.

Fusing these signals (audio, tactile, and inertial) raises confidence while reducing false positives.

FINE MOTOR SKILLS DEMAND MICRO-EDGE COMPUTE

It's tempting to assume the robot's "most intelligent" compute lives in the head or torso. In humanoids, the fastest intelligence must live where timing and interaction demand it: at the actuator and contact point. Tasks like slip detection, grip adjustment, pressure regulation, friction modulation, and micro-corrections unfold too quickly to tolerate a "ship data upstream, wait, then respond" architecture. Even a small delay can turn manipulation unstable: delicate parts get crushed, objects get dropped, and contact becomes unpredictable.

SOLVING THE TOUGHEST HUMANOID CHALLENGE: DEXTEROUS MANIPULATION

As humanoid robots move out of cages and into human environments, the capabilities in their hands will matter as much as the strength of their motors. Mastering the hand is what turns humanoids into truly general-purpose machines capable of operating in the messy variability of real industrial environments.

The humanoid hand is not just a mechanical marvel. It is where sensing, compute, and control converge. And in that convergence, the future of edge computing is being written ... one grasp at a time.

REAL-TIME MOTOR CONTROL: THE FOUNDATION OF HUMANOID MOVEMENT

Humanoid robots are often judged by how they move: a step that looks effortless, a reach that adapts mid-motion, a posture correction that happens almost invisibly. What makes this compelling is not strength or speed but coordinated degrees of freedom (DoF).

Modern humanoids integrate dozens of DoF across the body. Each adds capability, but also complexity. More joints mean more interaction, tighter coupling, and greater instability risk. Fluid motion is no longer a single command; it is emergent behavior sustained across the entire system. This is why humanoid movement is built from the ground up on real-time motor control.

DEGREES OF FREEDOM: POWER AND CONSEQUENCE

High DoF enable human-like movement: continuous posture adjustment, stable manipulation, and balance under disturbance. But coordination overhead scales rapidly. An error or delay in one joint does not stay local. It propagates through the body. A delayed ankle correction affects knee torque, a wrist disturbance shifts the shoulder, and a torso adjustment impacts overall balance.

WHY MOTION IS THE HARDEST PART OF INTELLIGENCE

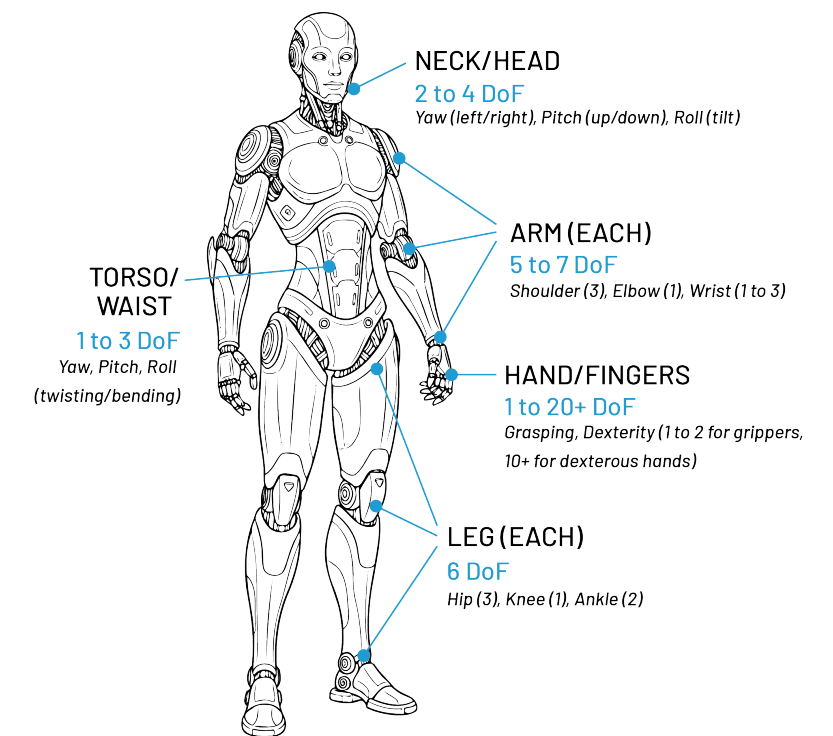
Humanoids continuously regulate force, torque, current, and position against gravity, inertia, friction, and external disturbances. Small timing errors can cascade into oscillation or instability, **making even standing still an active control problem.**

In high-DoF systems, minor inefficiencies repeated across joints quickly become visible strain. Effective motor control depends on:

- High-fidelity current sensing for smooth torque control
- Low-noise, integrated motor control loops for stable microcorrections
- Efficient, compact motor control architectures to reduce thermal and spatial constraints

Delivering this level of continuous regulation requires highly integrated motor control at the joint level. Modern humanoids increasingly rely on compact, real-time motor control solutions that combine current sensing, control loops, and motion sequencing within a single architecture. Solutions such as ADI

Figure 10: Humanoid—Degrees of Freedom Overview



Trinamic™ motor control platforms enable deterministic torque and velocity control with minimal latency, helping maintain stability even as system complexity scales. This level of integration is increasingly critical as humanoid designs push toward higher joint density without increasing system size or power budgets.

DETERMINISM STARTS WITH JOINT AWARENESS

Precise control begins with accurate joint position awareness. Humanoids rely on absolute sensing across both rotary (hips, knees, shoulders) and linear actuators (fingers, head).

This level of determinism increasingly requires multiturn absolute sensing. Technologies such as ADI's [ADMT4000](#) enable non-contact tracking of rotation, even when power is lost; eliminating external transducers and backup batteries while reducing actuator size and system complexity.

Crucially, absolute position awareness persists through power interruptions. Each joint retains its state, allowing control loops to resume deterministically from the first cycle without re-homing or fallback behavior. For complex systems, this is foundational to responsive and reliable operation.

TURNING DIGITAL INTENT INTO PHYSICAL MOTION

When a humanoid adjusts posture while reaching:

- The torso repositions to maintain balance
- Legs redistribute load
- Shoulders compensate for extension
- Wrists and fingers refine alignment

These corrections do not wait for centralized decisions. Learned policies



Precise control begins with accurate joint position awareness.

may define intent, but stable execution depends on deterministic motor control loops.

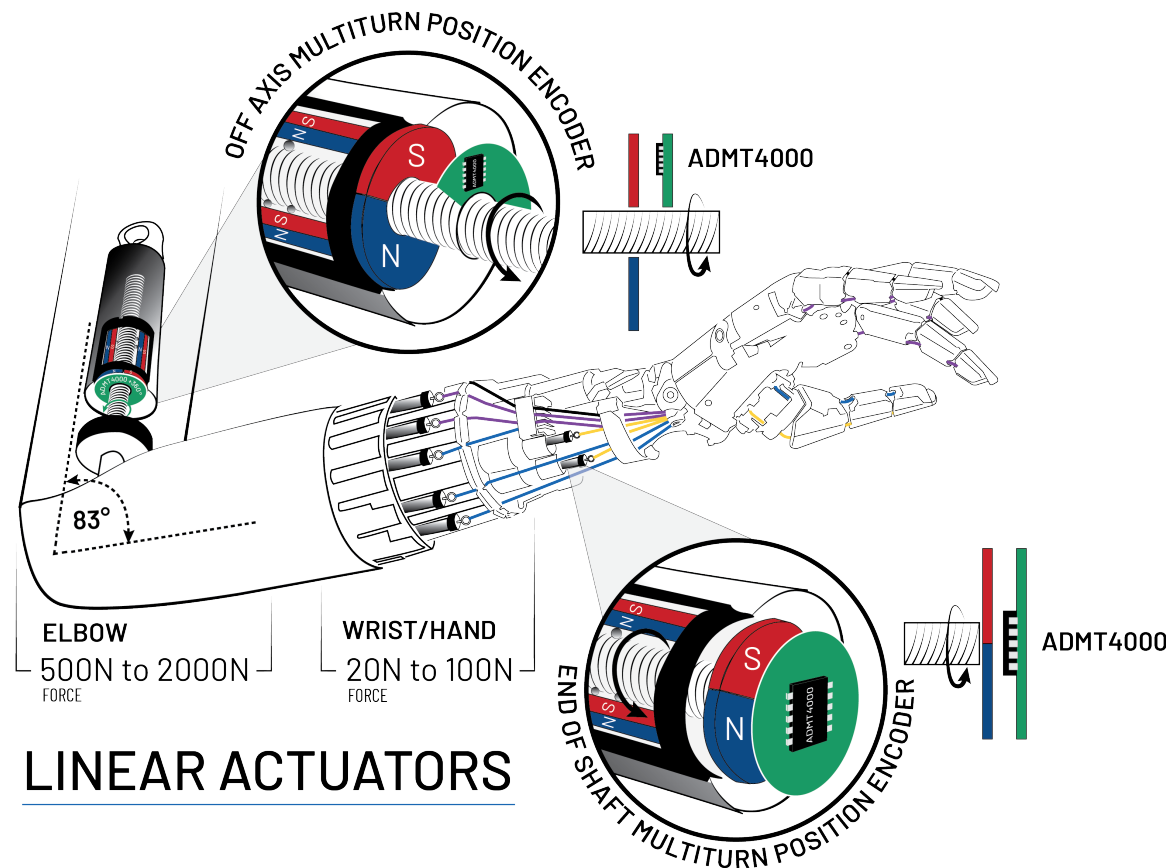
Motor control is where system capability becomes real within servo drives, joint modules, and embedded controllers that translate digital commands into smooth, safe motion. This is where highly integrated motor control solutions such as ADI Trinamic [TMC6460](#) play a critical role. By combining real-time control loops, current sensing, and motion control within a compact architecture, these solutions enable precise, low-latency execution at the joint level. When paired with robust position feedback, they provide the deterministic foundation required to coordinate dozens of joints without timing instability.

THE FOUNDATION OF INTELLIGENT MOTION

Humanoids will continue advancing in perception, connectivity, and high-level policy but none of it matters without precise execution. Intelligent motion is not defined by the number of degrees of freedom, but by how effectively those degrees of freedom are controlled, synchronized, and trusted.

That trust is built in the layers beneath—motor control, position sensing, and embedded intelligence—operating in sync to deliver stable, predictable motion in real time. This is the foundation on which intelligent motion is realized: one stable step at a time.

Figure 11: Multiturn Magnetic Sensing in a Tendon-Driven Humanoid Arm



HUMANOID ROBOTICS GROWTH PROJECTIONS	\$251.4B
	2035
	\$4.87B
	2025E

Source: Source: "Humanoid Robot Market Size, Share & Global Forecast 2026-2035"
<https://www.snsinsider.com/reports/humanoid-robot-market-1616>
February 16, 2026

REAL-TIME POWER MANAGEMENT: THE INTELLIGENCE THAT CONSTRAINS REALITY

In a tethered industrial robot, power is largely a solved problem. Plug in, size the supply appropriately, and move on. In humanoids, power is dynamic, constrained, and inseparable from behavior. Energy is no longer just fuel. It is a real-time system variable that shapes what a robot can do, when it can do it, and whether it can do it safely.

A humanoid is an **energy-bounded intelligence system**, reliant on the ability to accurately measure, predict, and manage its energy and thermal headroom while operating in dynamic, real-world conditions.

WHY ENERGY BECOMES THE DEFINING CONSTRAINT IN HUMANOIDS

Humanoids operate under conditions that make energy both scarce and unpredictable:

- Untethered operation with finite capacity
- Continuous stabilization and human-scale motion
- Task variability with changing load profiles
- Safety margins that cannot be violated

Energy is therefore tightly coupled to motion quality and safety. A low-margin power event does not simply reduce performance. It can create visible instability: a hesitant step, a degraded manipulation strategy, a hard stop, or a thermal cutback at the wrong moment.

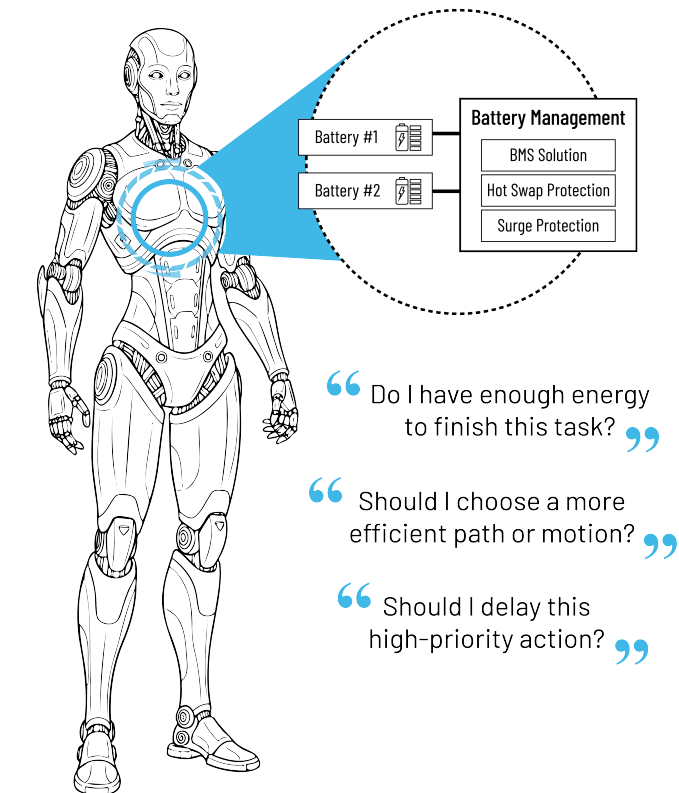
FROM POWER SUPPLY TO DECISION SYSTEM

The battery system is no longer passive. It is part of the autonomous control loop. At any moment, the system must answer:

- *Do I have enough reserve to finish this motion safely?*
- *Should I adjust my gait to avoid high-torque bursts?*
- *Can I lift this object without hitting a thermal or voltage limit mid-lift?*

These are not abstract planning questions. They are real-time physical constraints that require fast sensing, local estimation, and decision enforcement. In practice, the energy subsystem starts to behave like a copilot. It does not decide the robot's mission, but it continuously constrains and guides what is safe and feasible.

Figure 12: Humanoid Task Execution Evaluation



Energy consumption in humanoids is neither linear nor predictable. It is state-dependent and highly transient.

ENERGY-AWARE MOTION: NOT ALL BEHAVIORS COST THE SAME

Energy consumption in humanoids is neither linear nor predictable. It is **state-dependent** and highly transient:

- **Dynamic motion** (lifting, acceleration) creates peak current demands.
- **Locomotion** varies widely with gait efficiency and terrain.
- **Dexterous manipulation** drives high-rate sensing and compute loops.
- **Tool use** introduces unpredictable loads and vibration.

This means “remaining battery percentage” is not an actionable measure by itself. What matters is the robot's ability to translate energy state into **behavioral decisions**. An energy-aware humanoid can choose, in real time, between two actions that look similar at the task level but differ dramatically in risk and margin.

The emerging pattern looks like this:

1. Measure energy and thermal state continuously.
2. Predict the cost of candidate actions.
3. Select behavior that preserves stability and safety margins.
4. Enforce limits locally if conditions shift mid-action.

This loop mirrors the physical intelligence closed loop we defined in “Real-Time Robotics: The Rise of Physical Intelligence” on page 8, except the controlled variable is the **operating envelope**.

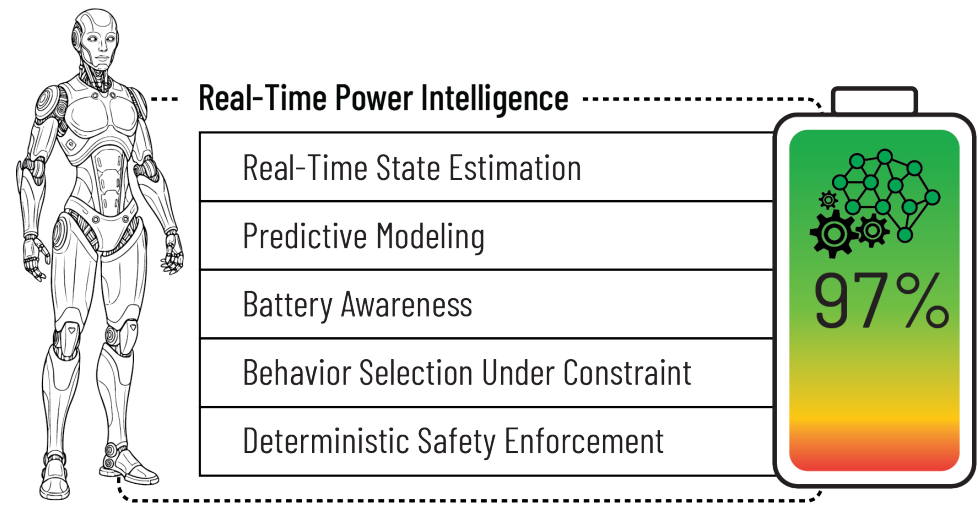
THE EMERGENCE OF REAL-TIME POWER INTELLIGENCE

For power to become part of autonomy, humanoids require a dedicated **energy intelligence layer** with five core capabilities:

- 1. **Real-Time State Awareness**
Knowing instantaneous demand, remaining usable capacity, temperature gradients, and safe discharge limits, not just average consumption.
- 2. **Predictive Modeling**
Estimating the energy and thermal cost of future motions and task sequences, including worst-case transients.
- 3. **Battery Awareness**
As batteries age and decline, the operating envelopes will have to be monitored and modified to take account of this. Battery monitoring capabilities are key to battery awareness. Click [here](#) for more information on ADI solutions.
- 4. **Behavior Selection Under Constraint**
Dynamically choosing gaits, manipulation or charge strategies, and compute modes based on energy and thermal headroom.
- 5. **Deterministic Safety Enforcement**
Refusing or modifying actions when margins are too low and doing so locally so the response is immediate and deterministic.

This follows the same architectural logic seen elsewhere in humanoids: central compute can plan, but safety-critical control must execute locally and on time.

Figure 13: Real-Time Power Intelligence Layers



ENERGY INTELLIGENCE IN REAL ENVIRONMENTS

Table 2 examines several real-world scenarios.

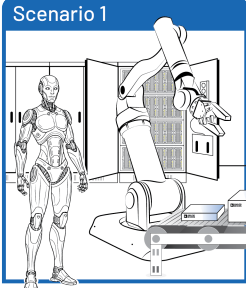
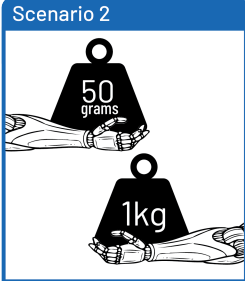
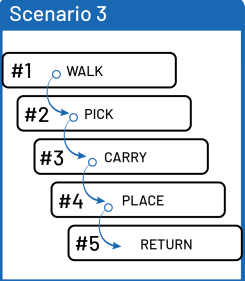
		
Scenario 1: Navigating a Factory Floor A humanoid is not just choosing a path. It is choosing an energy strategy. Inclines, friction, payload changes, and stop-start dynamics all matter. Energy-aware robots proactively adjust speed, routing, or timing to maintain margin.	Scenario 2: Lifting and Manipulation Before committing to a lift, the system evaluates peak current demand, voltage stability, and thermal headroom. If margins are insufficient, the robot adapts: changing posture, reducing acceleration, or deferring the action.	Scenario 3: Multi-Step Tasks True autonomy is not “can I execute step one?” It is “can I complete the entire sequence safely?” Walking, picking, carrying, placing, and returning must be evaluated as a continuous energy trajectory , not isolated actions.

Table 2: Energy Intelligence in Real Environments

ENERGY INTELLIGENCE AS A DIFFERENTIATOR

Energy-aware robots can operate longer with fewer mid-task failures and maintain more consistent motion quality as conditions change. They can also preserve thermal margin for safety-critical events and ultimately behave more predictably, which is essential for human trust.

Robots that treat power as a background utility will behave unpredictably under stress. Robots that integrate energy into their intelligence loop will behave consistently, safely, and predictably.

In humanoids, autonomy is not just about making decisions. It is about making decisions **within the bounds of physics every millisecond**. And energy is the variable that defines those bounds.

BALANCING INNOVATION AND SAFETY IN HUMANOID ROBOTICS



The loss of stability in a humanoid robot can introduce significant hazards, particularly when the robot is operating in close proximity to people.

Humanoid robots are no longer confined to research labs; they are beginning to appear in factories, warehouses, hospitals, and even public spaces. As we embrace this new generation of automation, one question becomes impossible to ignore: Are these robots safe enough to work alongside people?

Before answering the question of safety, let's start by introducing a new acronym DSIMR, which stands for dynamically stable industrial mobile robot. Uniquely, robots in this classification actively balance themselves and will fall over if they lose power. Humanoid robots fall into this category and may exhibit unpredictable recovery movements, creating the need for dedicated safety requirements.

In this chapter, we will explore the emerging safety challenges of humanoid robots and examine the technologies, safety functions, and standards that will help ensure they can operate safely alongside people. To help address these emerging challenges, a panel of experts within ISO Technical Committee 299 (Robotics) has begun developing a series of standards focused on the safe deployment of humanoid and other dynamically stable mobile robots. One of the first standards under development is [ISO/CD 25785-1, Robotics – Safety Requirements for Dynamically Stable Industrial Mobile Robots \(Legged, Wheeled, or Other Forms of Locomotion\) – Part 1: Robots](#). The standard is intended to provide requirements and guidance for risk reduction measures applicable to DSIMRs operating in industrial environments, helping manufacturers address the unique safety challenges posed by these highly mobile and adaptable machines. While not covered in any detail in this eBook, part 2 of the standard shall address safety requirements for the integration and application of DSIMRs.

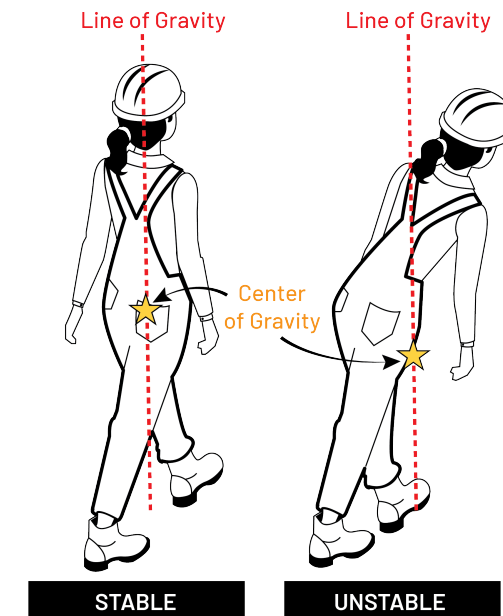
BUILDING UPON EXISTING STANDARDS

[ISO 10218-1:2025](#) defines an industrial environment as a “workplace where the public is restricted from access or is not reasonably expected to be present for the intended tasks and robot application(s).” As a result, the scope of ISO 25785-1 is limited to industrial applications and does not cover humanoid robots operating in public spaces. As humanoids move outside the factory and into social spaces, the standards will evolve to incorporate these workplaces but for now, humanoid standards focus on operating within industrial environments.

THE MECHANICS OF STAYING UPRIGHT

Most of us rarely think about what it takes to stay upright. Yet every step we take relies on a sophisticated balance system involving our brain, sensory organs, and musculoskeletal structure. Together, these systems continuously monitor and adjust our posture to keep our center of gravity above our base of support

Figure 14: Center of Gravity Basics



(the space between and including our feet). When the center of gravity moves outside this area, balance can no longer be maintained, and a fall becomes inevitable unless a rapid corrective action is made. Understanding this principle is essential when considering how humanoid robots achieve and maintain stability while operating in the real world.

Figure 15: [ISO 13855:2024](#)
Subclause 4.8

The loss of stability in a humanoid robot can introduce significant hazards, particularly when the robot is operating in close proximity to people. Unlike traditional industrial robots that are typically fixed in place, humanoid robots rely on dynamic balancing to remain upright and perform their tasks. As a result, ensuring their safe operation requires the development of novel risk reduction measures, including controlled stability functions, separation monitoring to maintain safe distances from people, and continuous stability monitoring to detect and respond to conditions that could lead to a loss of balance or a fall.

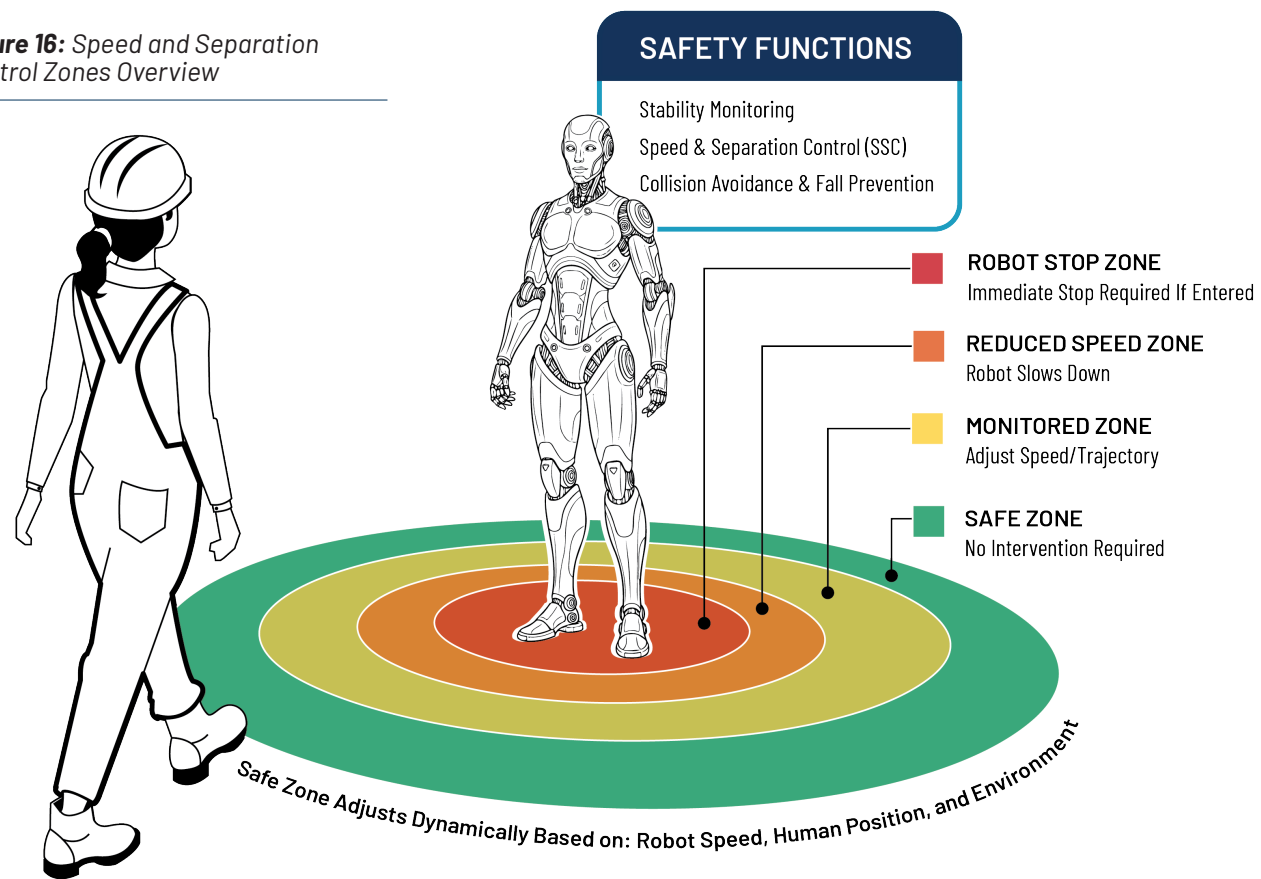
4.8 Speed and separation control (SSC)

SSC may be used to achieve the required risk reduction by maintaining the dynamic separation distance by appropriate adaptation of the speed or trajectory of the potential hazardous movements of the machine or its parts. The change of speed or trajectory of the hazardous movements of the machine or its parts can include causing a stop.

SPEED AND SEPARATION CONTROL (SSC)

To maintain the safe distance between humanoid robots and the human body requires the deployment of the **SSC safeguarding technique** described in [ISO 13855:2024](#). This approach reduces risk by maintaining a dynamic protective separation distance between the robot and a person, continuously adjusting the robot's speed, motion, or trajectory in response to human movement. If the separation distance falls below a predefined threshold, the robot can slow down, stop, or transition to a safe state before hazardous contact occurs.

Figure 16: Speed and Separation Control Zones Overview



To ensure people can work safely alongside humanoid robots, the safety functions responsible for preventing hazardous situations must be highly dependable. Whether monitoring stability, stopping functions, or maintaining safe separation distances, these functions should be designed and validated to meet the performance requirements defined by internationally recognized functional safety standards, including [ISO 13849-1](#), [IEC 62061](#), and [IEC 61508](#).

KEY TAKEAWAYS

Unlike traditional industrial robots, humanoids must maintain dynamic balance while moving through shared human environments. As a result, future safety frameworks will increasingly focus on stability monitoring, speed and separation control, functional safety, and motion-control systems. Emerging standards such as [ISO 25785](#) will be critical in ensuring that humanoid robots can safely coexist and collaborate with people in industrial settings.

ADI supports functional-safety development through rigorous product-development processes, a zero-defect culture, and in-house functional-safety expertise. This combination helps customers design toward third-party certification requirements while reducing system-development risk. Read more in Tom Meany's [Safety Matters technical blog series](#).



HUMANOIDS BEYOND THE DEMO: BUILDING ROBOTS THE REAL WORLD CAN TRUST

A humanoid robot is easy to admire when it walks, turns, reaches, or grasps with human-like fluidity. But the real measure of progress is not whether a robot can perform an impressive demonstration. It is whether it can operate reliably, safely, and repeatedly in real environments, alongside people, under uncertainty, and within the constraints of the physical world. That is the defining challenge of humanoid robotics.

A humanoid is not simply “AI in a body”. It is an integrated physical system where perception, connectivity, compute, motion, power, and safety must operate as one synchronized whole. The future of humanoids will not be determined by any single breakthrough, but by how well these technologies come together at the system level.

PHYSICAL INTELLIGENCE IS A SYSTEMS PROBLEM

Robotics is entering an era where innovation is compounding across sensing, compute, connectivity, actuation, energy, and safety. The key implication is not only that robots are becoming more capable. It is that the system loop is tightening.

A robot operating in the physical world must continuously sense, decide, act, observe, and adjust while the world remains in motion. Gravity, contact, inertia, friction, thermal limits, and human proximity all continue to apply. This is why physical intelligence is fundamentally different from traditional automation. It is not “think, then act.” It is a **continuous closed loop operating under timing and physics**. If that loop cannot run predictably, intelligence cannot be trusted.

WHERE CAPABILITY BECOMES TRUST

A deployable humanoid depends on intelligence operating across multiple layers, from real-time sensing and control to higher-level reasoning and planning:

- **System 0. Physical signal and actuation substrate, sub-5ms class:** sensors, actuators, joint state, motor currents, tactile signals, inertial measurement unit (IMU) updates, and low-latency local loops.
- **System 1. Fast interpretation and reflexive response, 5ms to 20ms class:** sensor fusion, slip response, balance correction, force adjustment, local motion control, contact modeling, and safety enforcement.
- **System 2. Cognitive reasoning and task planning, ≥50ms class:** route selection, human motion and intent prediction, task intent, policy-level orchestration, and planning.

Physical intelligence emerges when these layers operate as one coordinated system. Real-world performance depends on sensing, reasoning, and action remaining tightly synchronized. A disturbance at the ankle can propagate through the entire body. A slip at the fingertips can change arm loading. Even a delayed sensor stream or power fluctuation can compromise stability.

The result is a machine that must behave less like a collection of components and more like a **coordinated organism**, combining global intent with local reflexes.

That coordination starts with **perception**. Humanoids combine vision, tactile sensing, force and torque measurement, and other inputs to build situational awareness. No single sensing modality is sufficient; each complements and strengthens the others.

But perception alone does not create awareness. Sensor data must be synchronized and delivered predictably. **Connectivity** is more than a communications link. It functions as the robot’s nervous system, ensuring information is delivered where and when it is needed.

Motion is where this intelligence becomes physical. Every stable step, balanced posture adjustment, and successful grasp depends on deterministic motor control, accurate position awareness, and tightly coordinated feedback loops. Digital intent becomes physical action only when control is fast, stable, and repeatable.

Power is equally important. Unlike tethered industrial automation, humanoids operate within finite energy budgets. They must continuously evaluate battery state, thermal margins, expected workloads, and transient power demands. Energy awareness becomes a control variable, influencing how a robot moves, what tasks it performs, and how safely it operates.

Finally, trust ultimately depends on **safety** being engineered into every layer of the system. Humanoids must not only perform correctly under ideal conditions; they must respond predictably when conditions change.

Diagnostics, fault detection, bounded limits, deterministic behavior, and controlled degradation all contribute to machines that humans can confidently work alongside. Trust is earned when a machine remains understandable and safe, even when the unexpected happens.

FROM FACTORIES TO THE WIDER WORLD

The first large-scale deployments of humanoids are likely to happen in industrial and commercial environments, where tasks are high-impact, risks can be managed, and safety frameworks can mature alongside the technology. Factories, warehouses, logistics centers, hospitals, retail environments, and hospitality settings provide an important stepping stone between highly structured automation and open-ended domestic environments.



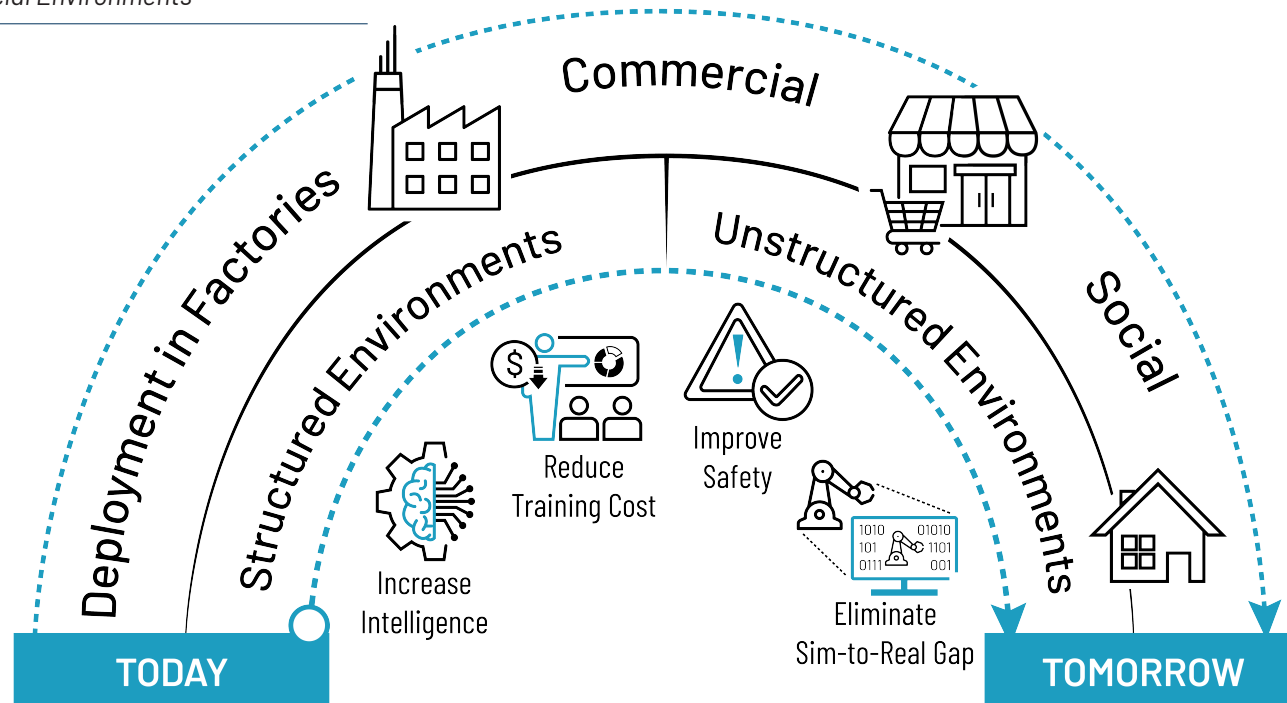
A robot operating in the physical world must continuously sense, decide, act, observe, and adjust while the world remains in motion.

These deployments will expose humanoid robots to increasing variability while still operating within manageable constraints, accelerating progress in the capabilities needed for broader adoption: richer intelligence, lower-cost training, stronger safety systems, and improved transfer from simulation to reality.

Eventually, those capabilities may enable humanoid robots to support people in homes and other social environments. But homes present a fundamentally different challenge. Every layout, routine, object, lighting condition, and interaction is unique. Success in these environments will require robots that can understand context, adapt continuously, and operate with a high degree of trustworthiness.

That future will not be achieved through demonstrations alone. It will be achieved through better systems engineering.

Figure 17: What It Takes for Humanoids to be Deployable in Social Environments



THE COMPLETE ROBOT

Two humanoid robots may share similar sensors, motors, batteries, and AI models, yet behave very differently in the field. The difference is the invisible layer: **system integration** that preserves timing, margin, safety, and awareness under real-world variability.

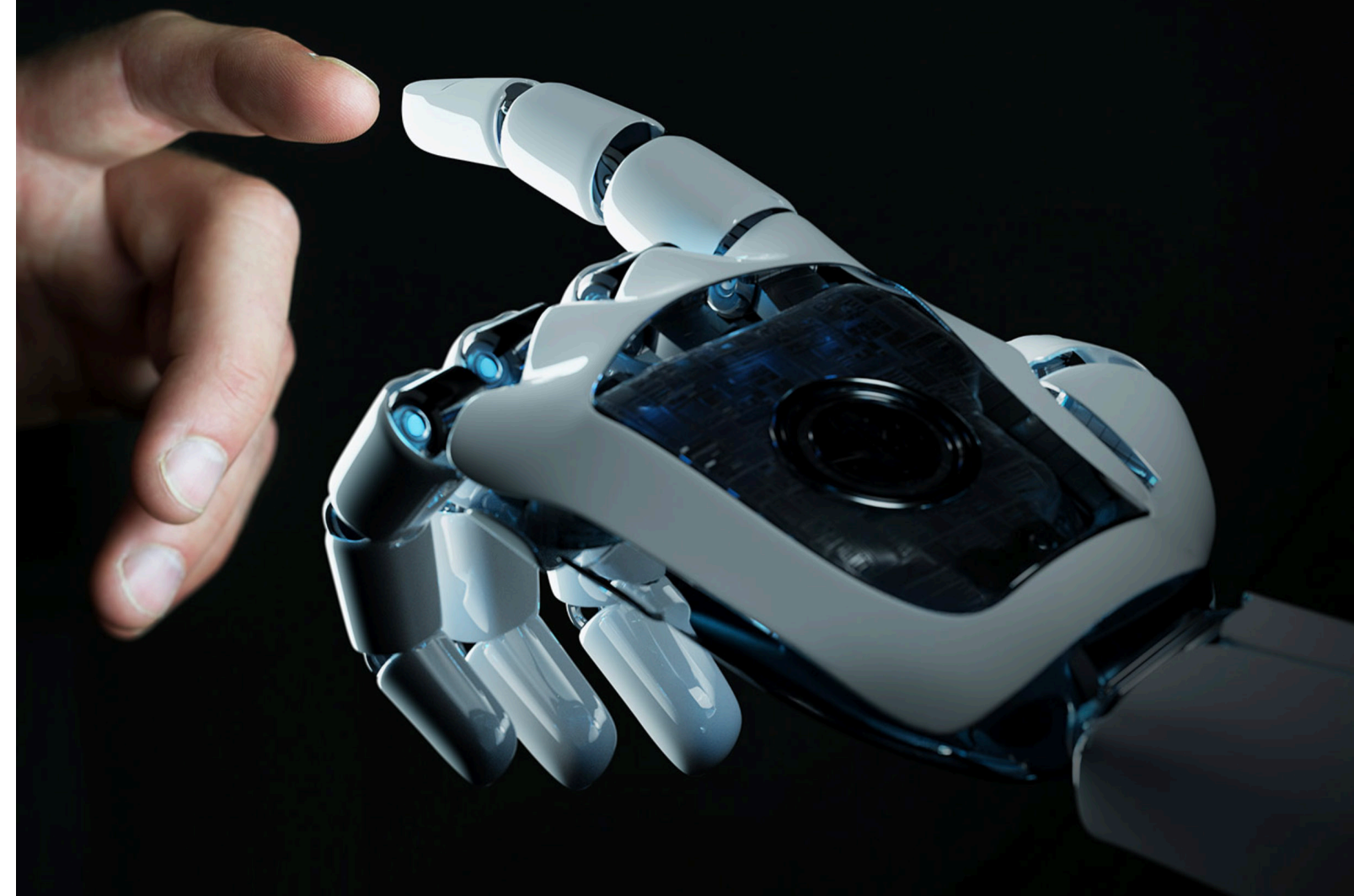
That is where the next phase of humanoid robotics will be won.

The future is not simply more intelligence. It is intelligence grounded in physics, distributed across the body, constrained by energy, synchronized through connectivity, executed through motion, and governed by safety. That is how humanoid robots move beyond spectacle and become trusted infrastructure.

"The future of robotics will be defined not by individual components, but by how seamlessly they work together. That future is already taking shape, and its foundation is **PHYSICAL INTELLIGENCE**."

Dara O'Sullivan

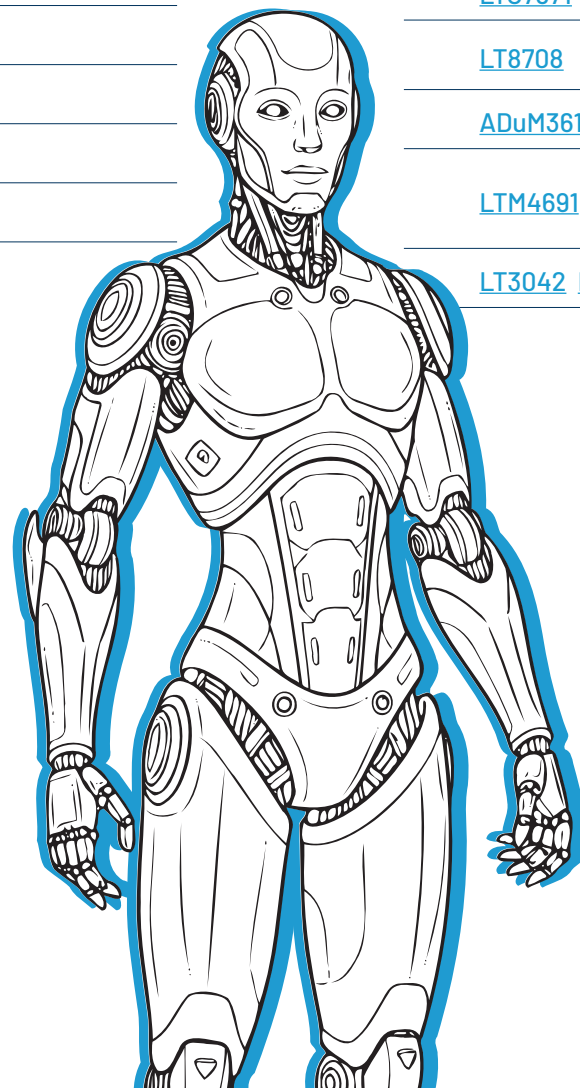
Director of System Applications,
Smart Machines & Robotics,
Industrial Automation,
Analog Devices



	CONNECTIVITY	SENSING	
3/6 Port Industrial Ethernet Time-Sensitive Networking Switches	ADIN3310 ADIN6310	ADMT4000	True Power-On Multiturn & Angle Position Sensor
2-Port Ethernet Switch with Integrated 10BASE-T1L PHYs	ADIN2111	MAX40109	Precision Signal Conditioning Pressure Sensor AFE
10BASE-T1S Dual Mode Ethernet to the Edge Bus (ADI E ² B) Transceiver	AD3300	AD4170-4	500kSPS Multichannel, Low Noise Precision Sigma-Delta ADC with integrated PGA
GMSL Serializer/Deserializer	MAX96717 MAX96724	AD4190-4	62.5kSPS Multichannel, Low Noise Precision Sigma-Delta ADC with integrated PGA
FPGA-Based 8x GMSL to 10Gb Ethernet Edge Compute Platform	ADRD8012-01Z	ENERGY AND POWER MANAGEMENT	
Robust, Industrial, Low Power 10BASE-T1S MAC-PHY	ADIN1140	ADBMS6948	16-Channel, Battery Pack Monitoring System
10Mbps, 100Mbps and 1Gbps Industrial Ethernet PHYs	ADIN1200 ADIN1300	LTC4287	High Power Positive Hot Swap Controller with Power Monitor
Robust, Industrial, Low Power 10BASE-T1L Ethernet PHYs	ADIN1100 ADIN1101	LTM4740	15A Step-Down μ Module Regulator
Robust, Industrial, Low Power 10BASE-T1L Ethernet MAC-PHY	ADIN1110 ADIN1111	LT8418	100V Half-Bridge GaN Driver with Smart Integrated Bootstrap Switch
	MOTION	AD8410A	High Voltage, High Bandwidth Current Sense Amplifier
Fully Integrated Field-Oriented Control Brushless DC Driver	TMC6460	LTC4364	Surge Stopper with Ideal Diode Controller
70V Smart Gate Driver with Servo (FOC) Controller in Hardware and Buck Converter	TMC9660	MAX17614	Ideal Diode/Power Source Selector with Current Limit, UV, OV Protection
	PERCEPTION	LTC7821	Hybrid Step-Down Synchronous Controller
1 MegaPixel Time-of-Flight Module	ADTF3175	LTC7871	Six-Phase, Synchronous Bidirectional Buck or Boost Controller
Time-of-Flight Depth Image Signal Processor (ISP)	ADSD3500	LT8708	80V Synchronous 4-Switch Buck-Boost DC/DC Controller
Precision, Miniature MEMS IMU	ADIS16500	ADuM361N	5.7kV/3.0kV rms 6-Channel Digital Isolator
Wide Dynamic Range, Miniature MEMS IMU	ADIS16470	LTM4691	Low V_{IN} , High Efficiency, Dual 2A Step-Down DC/DC μ Module [®] Regulator
Evaluation Board for ADIS16470 and ADIS16500	EVAL-ADRD2121-EBZ	LT3042 LT3045	Ultralow Noise, Ultrahigh PSRR Linear Regulator

These products represent selected ADI technologies relevant to humanoid sensing, connectivity, motion, and power architectures.

Product suitability depends on system requirements, operating conditions, and design configuration.





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