

# Choosing the Right Battery Architecture for Humanoid Robotics and Physical AI



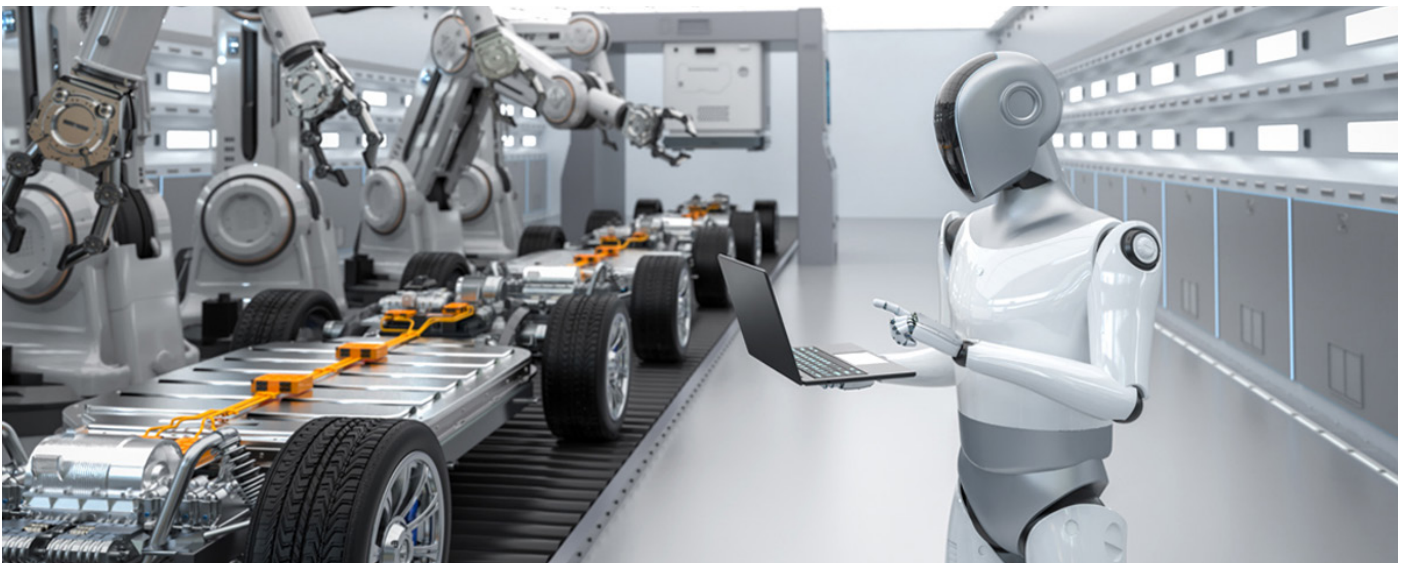
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Today, autonomous vehicles, drones, and other mobile platforms are becoming increasingly common in smart warehousing and supply chain operations, where they often rely entirely on batteries to power motors, sensors, and onboard computing.

In the coming decade, humanoid robotics and physical AI are tipped to become another transformative technology<sup>1,2</sup>. These systems represent a major step beyond traditional robotics which operate in controlled environments and typically rely on fixed infrastructure.

In comparison, humanoid robots and other physical AI systems are designed to mimic human activity in complex, real-world tasks and must operate untethered while navigating dynamic environments.

To achieve this, they require substantial onboard power to support locomotion, sensing, and real-time edge processing.



*Image source: Canva.*

Every action draws significant energy: from balancing to moving, to interaction and manipulation all happens while also performing continuous AI inference for awareness, contextual reasoning and reaction. As a result, battery technology is a critical enabling technology.

Humanoid robot batteries typically have capacities between 0.5 – 5 kWh, which translates to battery packs weighing up to 30 kg. Even with larger packs, most humanoid robots currently deliver only 1 to 3 hours of active runtime. Therefore, even small improvements in performance, efficiency, and weight savings can make a meaningful difference. This is why battery architecture is a critical factor in determining robot runtime, productivity, and reliability.

# Why Battery Design is Critical for Humanoid Robots

Space and weight distribution must be carefully managed, but cells are inherently heavy, and their placement directly affects the robot's center of gravity, balance, and mobility. Engineers must consider weight distribution across the robot's body to ensure stable walking and efficient movement.

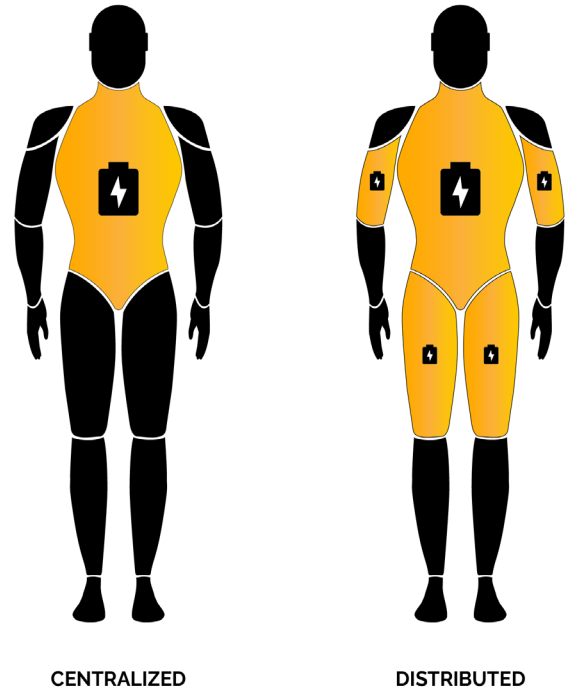
This includes design approaches such as:

**Centralized battery packs**, typically located in the torso, they simplify battery management but can create balance challenges by raising the centre of mass.

**Modular/distributed battery systems** placed around the robot may improve balance, but also introduce complexity in power distribution, wiring, and charging infrastructure.

Both these options must also include charging equipment, and support **safety-focused** fast charging to minimize downtime.

**Replaceable batteries** can avoid fast-charging constraints, but they must also consider handling equipment, long-term durability of repeated swaps, and accessibility requirements that may limit battery placement.



*An example of centralized versus distributed battery placement in a humanoid robot.*

Any battery over 2 kWh will also be subject to regional regulations, such as the EU Battery Passport, which requires supply chain tracking, state-of-health accessibility, and reuse or recycling considerations.

## Limitations of Traditional Centralized Battery Architectures in Robotics

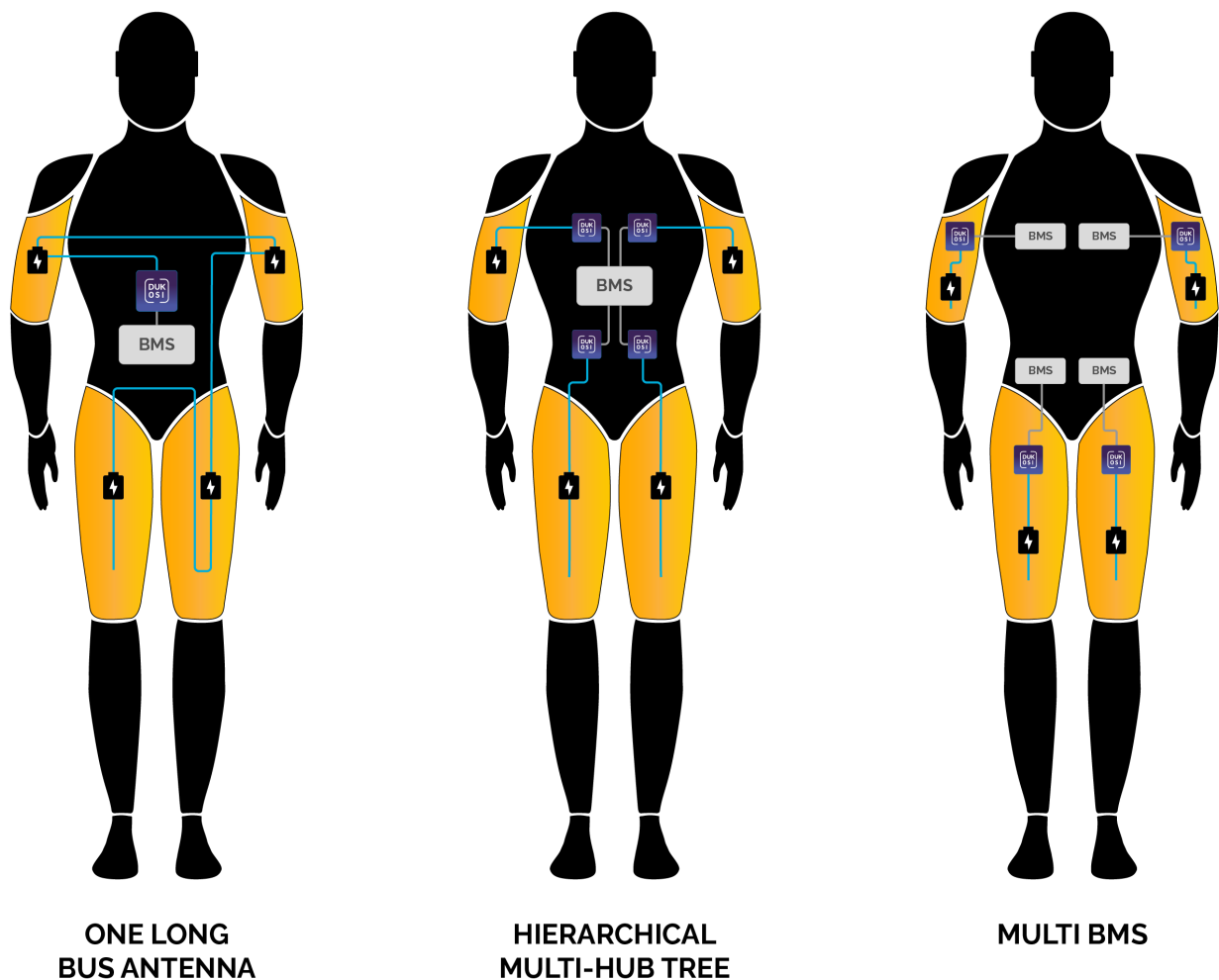
These options require batteries that conform to a robot's structure or operational activity in ways that traditional pack architectures cannot easily support. Most modern battery systems are designed as single, fixed structures where cells are wired into contiguous modules, with multiple modules grouped into a pack to reach appropriate voltage or power levels. However, distributing energy storage across multiple independent packs can introduce packaging inefficiencies and increase wiring complexity and cost. What robotics designers increasingly need is a way to build a flexible, distributed energy storage system while minimizing wiring and maintaining a unified battery management system.

# A Distributed Battery Architecture for Robotics and Physical AI Systems

Instead of requiring all cells to be housed within a single rigid pack, some humanoid robotics developers want to distribute batteries around the body, housing them closer to the actuators to take advantage of weight distribution, reduced power wiring, or because it's an opportunity to use the space for more energy storage.

In addition to supporting traditional centralized battery storage systems the Dukosi Cell Monitoring System (DKCMS®) is unique in supporting distributed cell clusters, appearing to the system as one cohesive battery, which greatly simplifying power management. Alternatively it can operate as several smaller batteries while also minimizing wiring, and weight. This unparalleled flexibility allows engineers to better align their energy storage needs with mechanical design preferences, or constraints.

Using Dukosi's smart cell technology enables direct cell-level measurement of voltage and temperature, ensuring operational safety and highly accurate cell monitoring leading to more useable energy per cell. This high-resolution cell-level data fuels new levels of diagnostics, performance optimization, and predictive safety and maintenance.



An example of possible integration methods of DKCMS into a humanoid robot with a distributed battery system.

Using near field 'contactless' connectivity and Dukosi's C-SynQ® means the cell data communication is extremely robust, reducing reliance on physical connectors and solder joints that may degrade under repeated movement and vibration, while also having comprehensive robustness mechanisms capable of withstanding high levels of external EMI disturbances.

Its unique single bus antenna for cell-to-BMS communication means DKCMS eliminates unreliable and heavier wiring used in traditional modular battery architectures, allowing this flexible communication antenna to be routed throughout every distributed cell cluster, or separate shorter communication antennas can be spurred from a central BMS location into each cluster. This scalability and flexibility are unmatched among battery architectures. Meanwhile, high-voltage and low-voltage components are inherently separated, simplifying safe routing in space-constrained designs, improving safety and reliability.

Using Dukosi's C-SynQ communication protocol<sup>3</sup> means the system transmits all cell data synchronously and with deterministic latency to the BMS processor enabling it to accurately calculate State of Charge, Available Power, and Health<sup>4</sup>, while also monitoring the temperature of every cell<sup>5,6</sup>. This is particularly valuable in distributed systems where charge/discharge thermal conditions may vary depending on actuator use or environmental exposure.

Changes to battery design, including layout, cell size, capacity, or chemistry<sup>7</sup>, can be readily accommodated without revalidating the entire system, accelerating development, prototyping, and time to market.

## References

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Dukosi Ltd develops revolutionary technologies that dramatically improve the performance, safety, and efficiency of battery systems, and enable a more sustainable battery value chain. The company provides a unique cell monitoring solution based on chip-on-cell technology and C-SynQ® communication protocol for electric vehicles (EV), industrial transportation and stationary battery energy storage markets.

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