Humanoid Robot Reference Guide

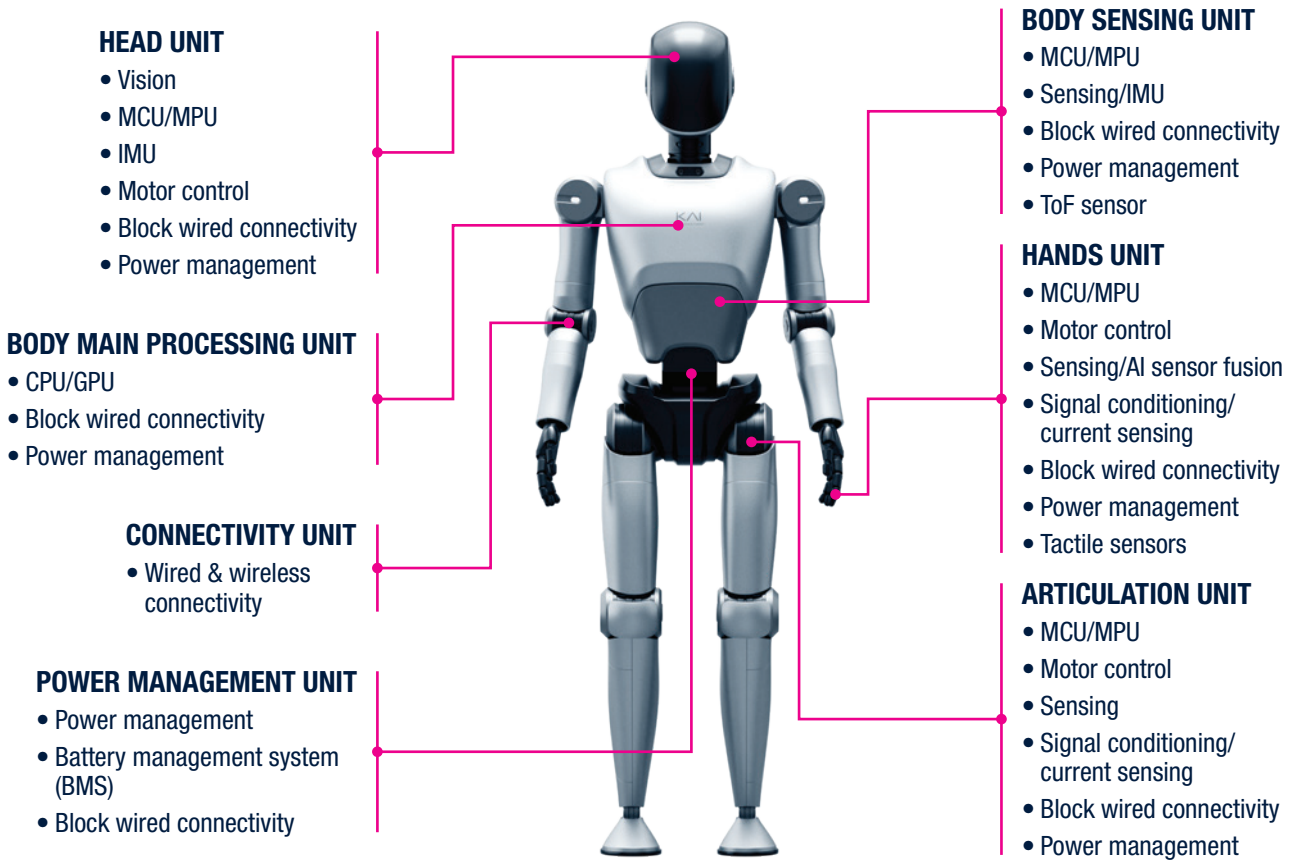
Contents

Introduction

Humanoid robots are transforming industries by taking on tasks that once required human effort—from service operations to advanced automation. Behind this innovation lies a foundation of cutting-edge semiconductor technologies that ensure performance, safety, and efficiency.

The architecture of the humanoid robot lends to strategic repetition of sub-system design and components, bringing multiple technologies together including power management, motor control and sensing to enable PhysicalAI at the edge. Through STMicroelectronics diverse portfolio that has been cultivated with a system solution approach enable customers to integrate seamlessly between each technology.

STMicroelectronics empowers designers with a broad portfolio of products and a complete ecosystem of hardware and software tools, enabling faster, smarter development of humanoid robot solutions.

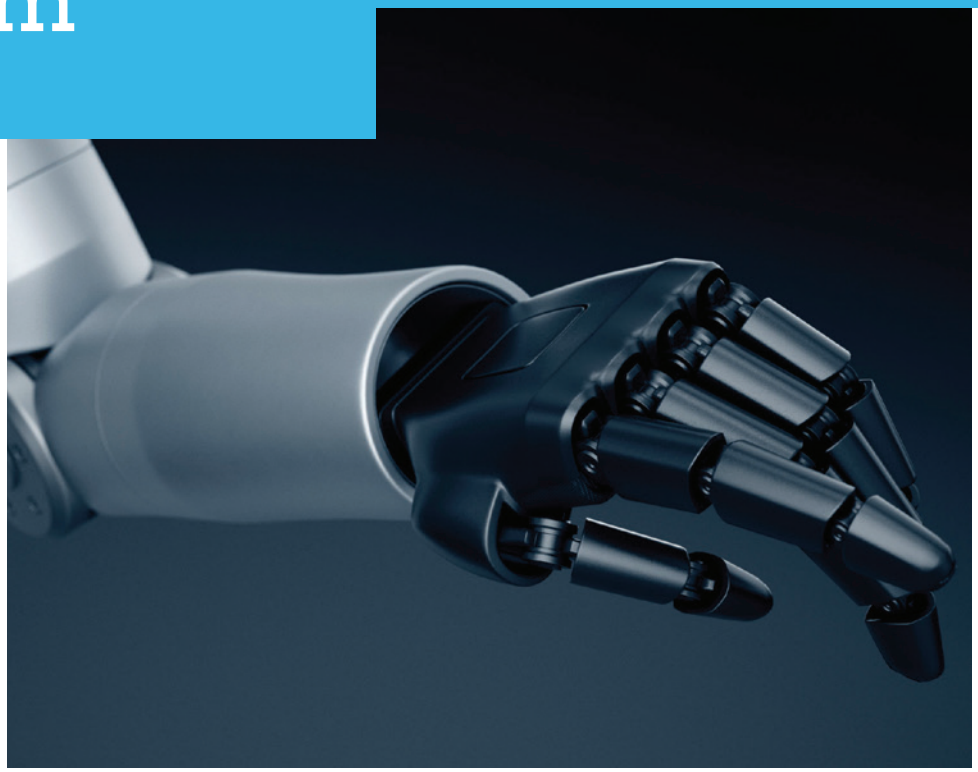


This document follows the structure below:

- Body Sensing unit subsystem
- Articulation unit subsystem
- Body main processing unit subsystems
- Hands unit subsystem
- Power management unit subsystem
- Connectivity unit subsystem
- Head unit subsystem
- Backbone components

In the **Backbone chapter**, will be described, embedded security, zonal processor, memories ICs.

Body Sensing unit subsystem



Introduction

Sensing is essential for reliable operation, whether in harsh industrial environments or human-centric settings. Achieving this requires a sophisticated fusion of multiple sensor technologies that emulate key human senses, such as:

Orientation and Movement: Utilizing MEMS (Micro-Electro-Mechanical Systems) inertial sensors to provide precise kinematic feedback and balance control.

Tactile and Environmental Perception: Capturing touch, vibration, and audio to interact naturally with the world.

Proximity and Spatial Mapping: Integrating ToF (Time-of-Flight) sensors within the body sensing structure to enable high-resolution distance measurement and 3D awareness.

Integrating these technologies allows a robot to transition from a "blind" machine to an entity with spatial and physical self-awareness.

MEMS act as the "inner ear" and "nervous system" for the robot, providing internal and surrounding feedback, implementing following features:

Inertial Navigation (IMUs): By combining MEMS accelerometers and gyroscopes, the robot maintains its balance. It can detect the slightest tilt or acceleration, allowing for dynamic gait stabilization (preventing falls).

Acoustic Sensing: MEMS microphones enable localized sound recognition, allowing the humanoid to turn its head toward a human speaker or identify structural vibrations that indicate mechanical stress.

ToF (Time-of-Flight) Sensors serves as the "proximity sense" or "short-range vision," creating a safety bubble around the robot; implementing following features:

Obstacle Avoidance & SLAM: ToF sensors emit light pulses to calculate distance based on the time it takes for the pulse to return. This allows for real-time 3D mapping of the immediate surroundings.

Hand-Eye Coordination: During manipulation tasks, ToF sensors in the wrists or palms provide high-precision distance data to objects, ensuring the robot doesn't crush delicate items or miss a grasp.

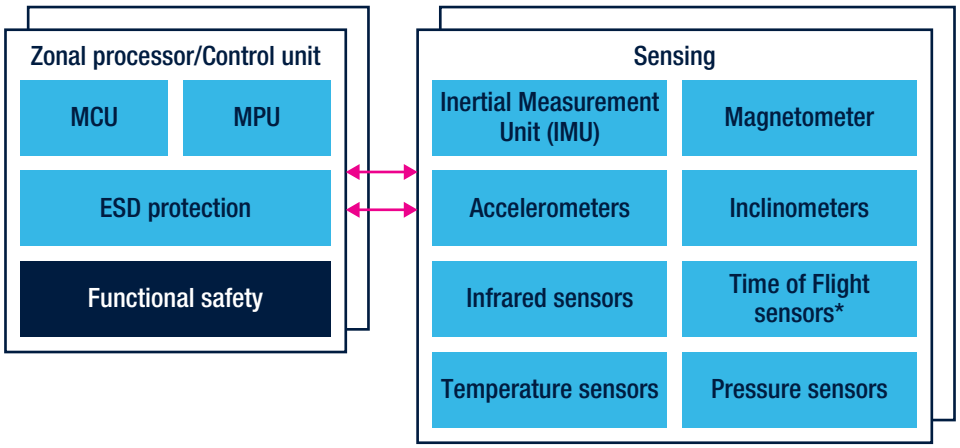
Human-Robot Interaction (HRI): They detect the presence and movement of people nearby. Unlike traditional cameras, ToF sensors work in low-light conditions by processing depth data rather than high-resolution images.

SUBSYSTEM BLOCK DIAGRAM

Humanoid robots rely on a network of body sensing units positioned across limbs, torso, head, and extremities.

These units integrate diverse sensors—IMUs, accelerometers, magnetometers, vibration, temperature, pressure sensors, inclinometers, and more—to capture motion and environmental data.

To ensure seamless communication and remote monitoring, sensors connect to microcontrollers via standard interfaces such as I2C and SPI.



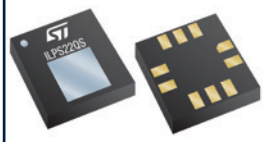
Note: * sensor details to the paragraph Head unit

ST MEMS PRODUCTS

STMicroelectronics offers a comprehensive portfolio of micro-electromechanical systems (MEMS) tailored for humanoid robotics.

These include accelerometers, gyroscopes, magnetometers, and environmental sensors—critical for enabling orientation, movement, and perception in robotic systems.

Designed for high performance, reliability, and energy efficiency, ST MEMS solutions support advanced functionalities such as motion tracking, environmental awareness, and responsive interaction, helping developers build robots that operate safely and intelligently in dynamic environments.

IMU	IMU Asil B	Vibration & Inclinometer	Pressure	Magnetometer
				
ISM330DHCX ISM330IS ISM6HG256X	ASM330LHHXG1 ASM330LHBG1	IIS3DWB	ILPS22QS ILPS28QSW	IIS2MDC

IMU

Inertial Measurement Units (IMUs) combine accelerometers and gyroscopes in a compact 6-axis system, delivering precise orientation and motion data essential for humanoid robotics.

By integrating multiple sensor outputs, ST IMUs achieve the high accuracy required for advanced balance control, movement coordination, spatial awareness, and other robotic functions.

The latest generation of ST IMUs includes embedded machine learning cores (MLC) for context awareness, enabling low-power edge processing. Combined with a finite state machine (FSM), these features allow real-time analysis of motion patterns and activities—critical for responsive and intelligent humanoid robots.

Part number	Package	Sensing axes	Acceleration range (g)	Angular rate range (°/s)	Supply voltage (V) max	Angular rate noise density (°/s / √ Hz)
ASM330LHBG1	LGA 14L 2.5x3x0.86 mm	X, Y, Z, Yaw, Pitch, Roll	±16, ±2, ±4, ±8	±4000	3.6	0.005
ASM330LHHXG1						
ISM330BX	LGA 14L 2.5x3x0.74 mm		±2, ±4, ±8			0.0045
ISM330DHCX	LGA 14L 2.5x3x0.86 mm		±16, ±2, ±4, ±8			0.005
ISM330DLC				±2000		0.0038
ISM330IS						0.0034
ISM6HG256X			±128, ±16, ±2, ±256, ±32, ±4, ±64, ±8	±4000		0.0045

Pressure sensors

ST MEMS pressure sensors deliver high performance with ultralow power consumption under 4 µA, which contributes to battery autonomy in humanoid robots.

They feature enhanced temperature compensation and support two selectable full-scale ranges: 260 to 1260 hPa for standard atmospheric sensing, or an extended range up to 4060 hPa (≈ 4 bar) for applications requiring higher pressure monitoring.

This flexibility is enabled by advanced ST sensor architecture and calibration, allowing developers to configure the device for the environment and application needs.

Thanks to ST's unique full-molded package design, these sensors offer maximum reliability and exceptional resistance to degradation, ensuring long-term durability in demanding robotic systems.

Part number	Package size (mm)	Pressure noise (hPa) RMS	ODR (Hz) max	Operating pressure (hPa) max
ILPS22QS	2x2x0.73	0.0034	200	4060
ILPS28QSW	2.8x2.8x1.95	0.0032		

Magnetometer

In humanoid robots magnetic sensing provides absolute heading and orientation data that complements accelerometers and gyroscopes for precise motion control. Integrated into sensor fusion systems, magnetometers help maintain balance, improve localization, and ensure reliable performance.

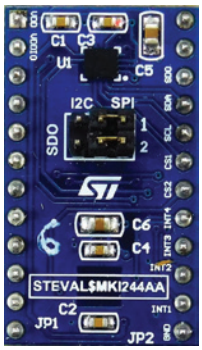
ST MEMS magnetometers offer a compact and innovative solution for magnetic field sensing. These sensors leverage advanced microfabrication technologies to deliver high precision, low power consumption, and miniaturized form factors, making them ideal for robotics applications, as well as for portable devices, wearables, drones, and IoT.

Often integrated with IMU accelerometers and gyroscopes in multisensor modules, ST MEMS magnetometers provide comprehensive orientation and motion data. Their robust design and sensitivity enable reliable operation even in environments with strong electromagnetic interference.

Part number	Package	Sensing axes	Magnetic range (Gauss) typ	Supply voltage (V) max
IIS2MDC	LGA 2x2x0.7 12 leads	X, Y, Z	±49	3.6

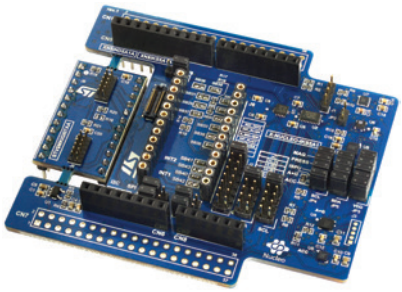
TURNKEY SOLUTIONS

STEVAL-MKI244A



Adapter board for Nucleo expansion board supporting ASM330LHBG1.

X-NUCLEO-IKS5A1

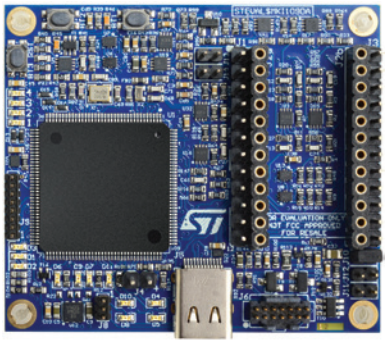


The X-NUCLEO-IKS5A1 is an industrial motion MEMS and environmental sensor evaluation board kit, it allows application development with features like FSM, MLC, ISPU, and sensor hub (with ISM330IS and ISM6HG256X onboard).

STEVAL-MKI223V1K

The STEVAL-MKE001A, STEVAL-MKE002A, or STEVAL-MKE003A electrode boards can be stacked on the STEVAL-MKI223V1 board. The kit provides the complete ILPS28QSW pinout. This adapter is supported by the STEVAL-MKI109D evaluation platform.

STEVAL-MKI109D



STEVAL-MKI109D is an evaluation platform that allows engineers to monitor the behavior of ST MEMS sensors and maximize the performance of new product designs, accelerating time to market. This board is compatible with ST MEMS adapter boards and supports I2C, I3C, SPI, and TDM communication interfaces for very high output data rates.

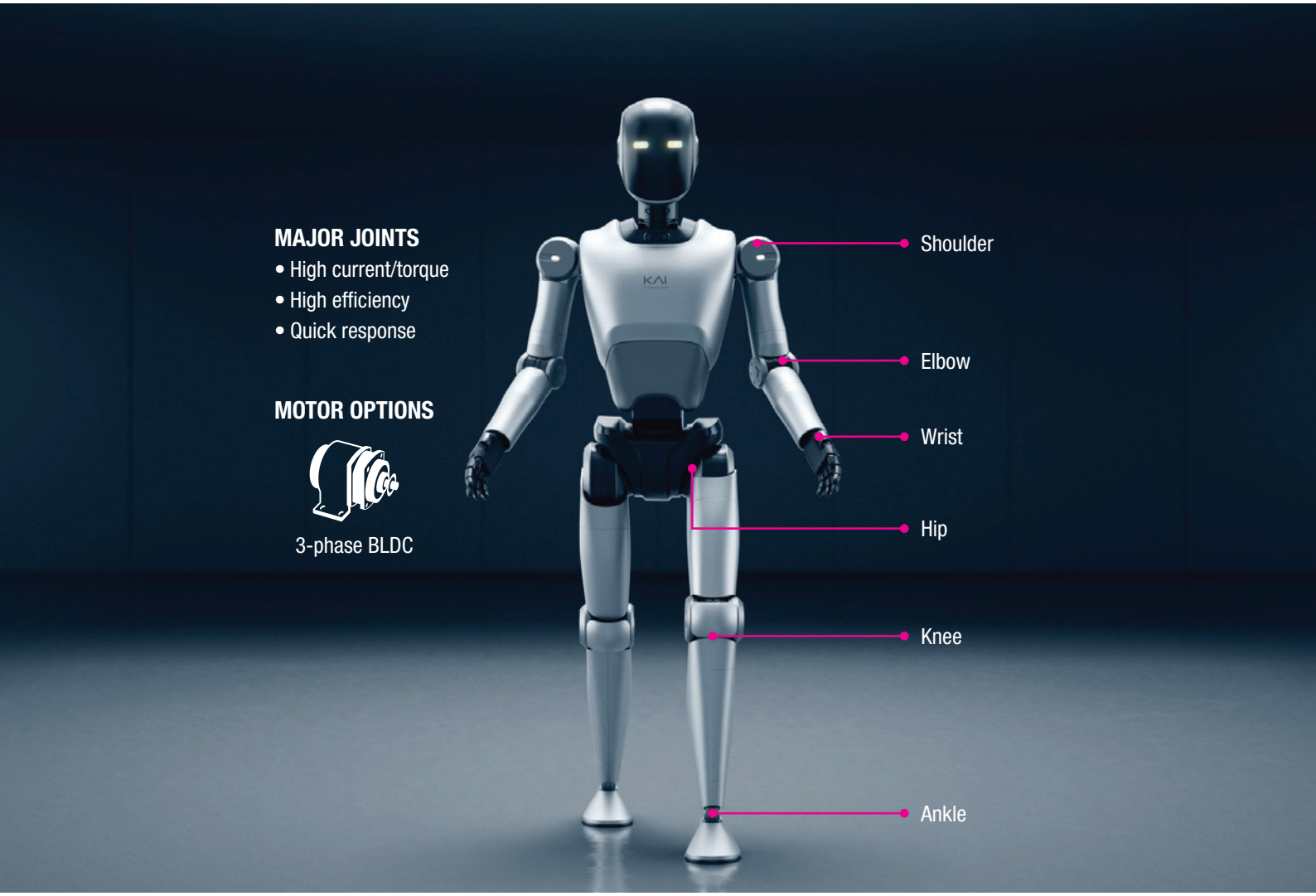
Articulation unit subsystem

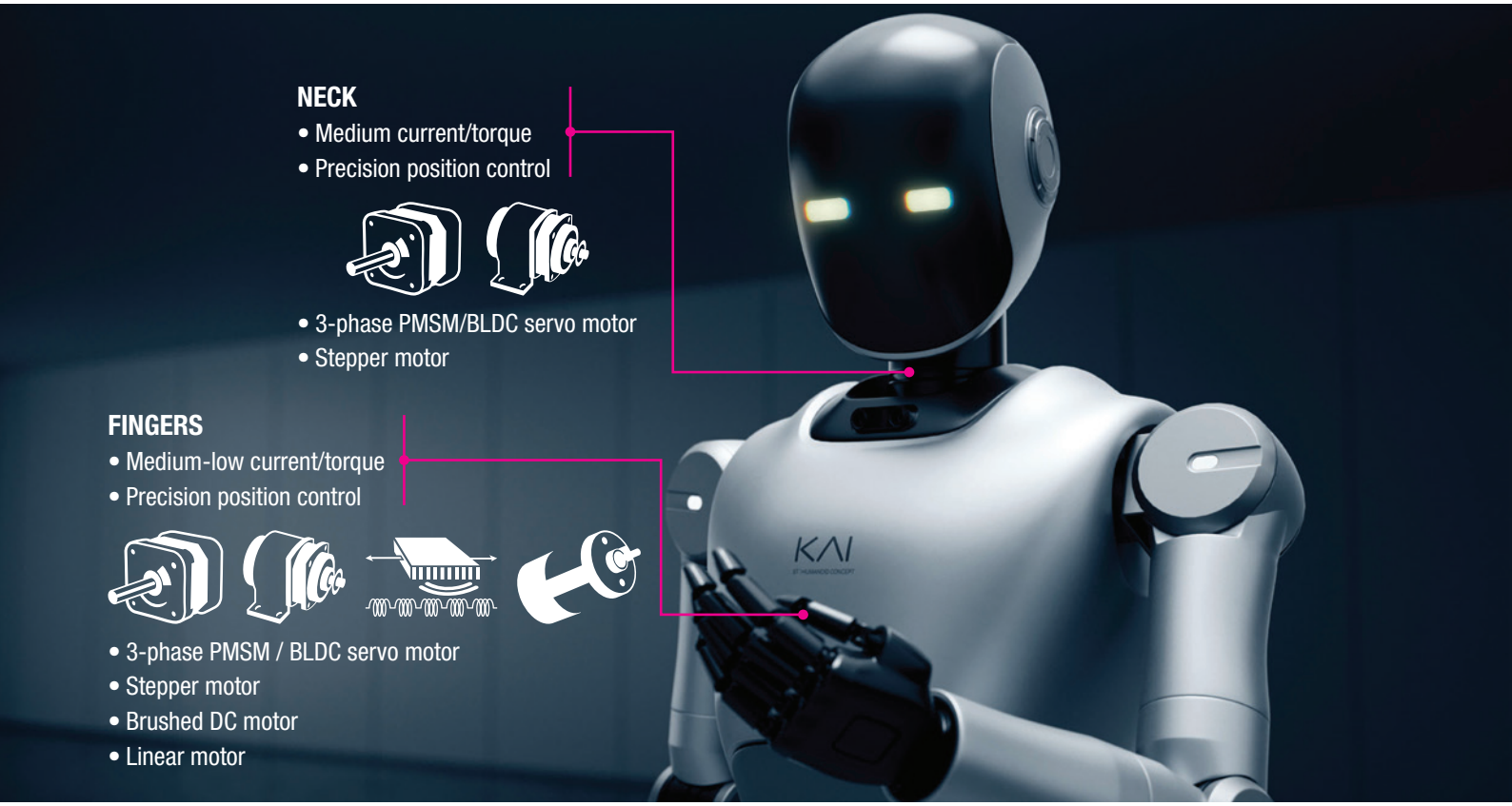
Introduction

Humanoid robots require precise, reliable motor control for major joints, neck, and fingers—critical for achieving smooth, human-like movement. STMicroelectronics provides tailored solutions for motors operating from 12 V to 48 V, ensuring flexibility across different robot designs.

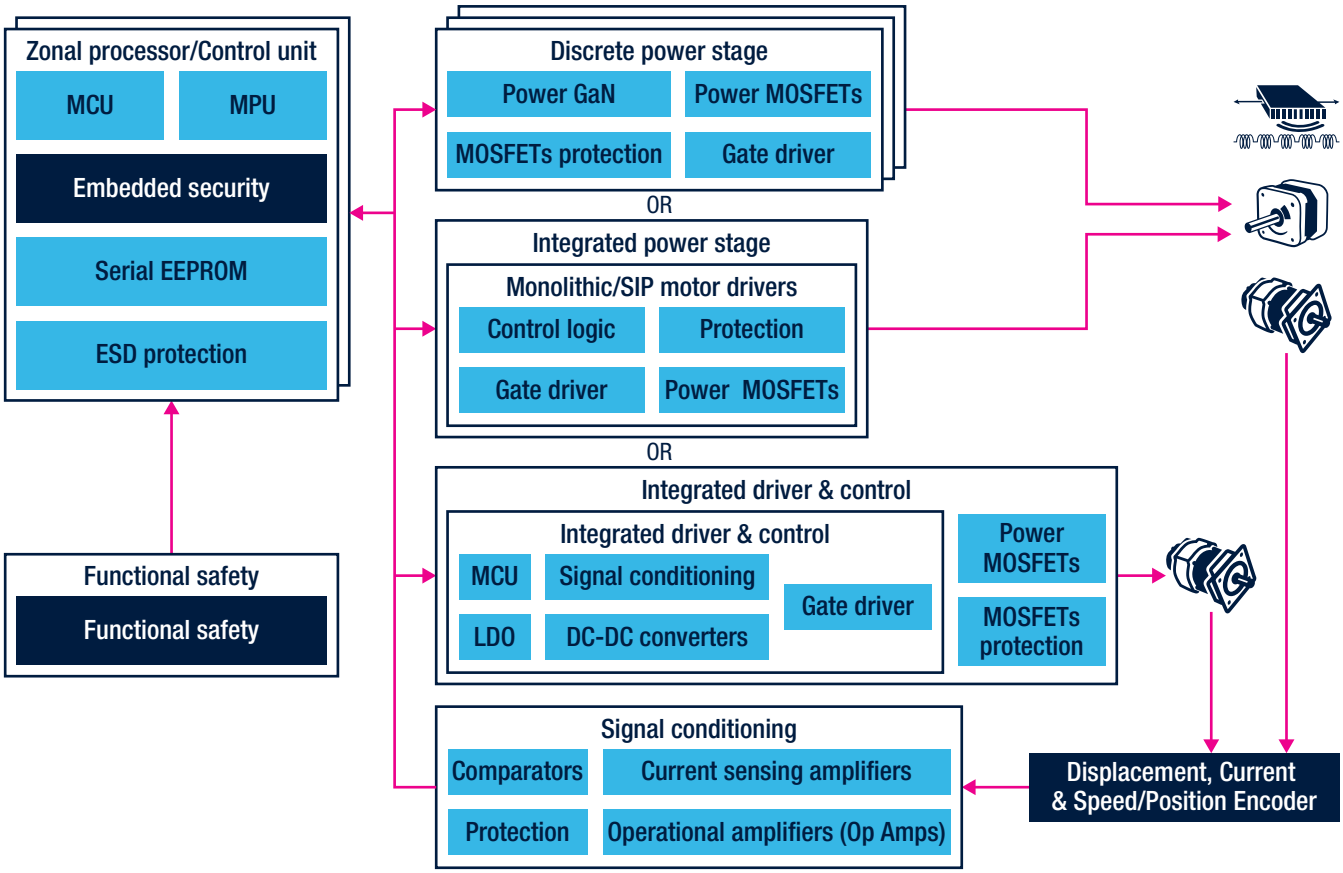
These systems typically use three-phase permanent magnet motors (BLDC, PMSM, PMAC), driven by a PWM-controlled three-phase bridge (three half-bridges), in some cases, in particular for hands also coreless DC motors are used. This architecture enables variable frequency and voltage, delivering accurate torque and speed control for natural motion.

ST supplies the essential components for this setup, including monolithic driver ICs, power MOSFETs, IGBTs, gate drivers, power modules, and dedicated microcontrollers—optimized for efficiency, safety, and scalability.





SUBSYSTEM BLOCK DIAGRAM



Main products

MCU	Motor Drivers ICs	Gate Drivers	Power MOSFETs
			
STM32H7 STM32F7 STM32G4 STM32H5	STSPIN830 STSPIN32G4 STSPIN958/9P1 powerSTEP01	STDRIVE101 STDRIVE131	F7 family

See the **Motor Control Reference Guide** for details on ST products for motor control.

MCU SELECTION GUIDE FOR HUMANOID ROBOT MOTOR CONTROL

Motor	STM8S	STM32G0 STM32F0 STM32F1	STM32G4 STM32F41x STM32F3 STM32L4 STM32H5	MPU STM32H7 STM32F7 STM32F4
Brushed DC Motors	•	•	•	•
Stepper Motors	•	•		
3-phase PMSM/FOC - vector control		•	•	•
3-phase BLDC/6-step	•	•	•	•

STM8S:
Brushed DC motors

STM32:
Stepper motors
3-phase brushless motors

MOTOR DRIVER ICs

Humanoid robots demand precise, reliable motor control to achieve smooth, human-like movement across multiple joints. **STSPIN motor drivers** address these challenges by embedding all essential functions for efficient and accurate actuation. An **integrated motion profile generator** reduces the computational load on the host microcontroller, while comprehensive protection and diagnostic features ensure long-term reliability in demanding environments.

To meet the requirements of complex robotic motion, many STSPIN ICs implement **adaptive current decay control** and **voltage-mode driving** for micro-stepping motors. These techniques enhance **torque accuracy and motion smoothness**—critical for natural limb articulation and fine motor control. Scalability and modularity allow STSPIN solutions to fit diverse system architectures, supporting voltage ranges and mechanical configurations common in humanoid designs. **Thermally optimized, space-saving packages** further enable integration into compact robotic assemblies without compromising performance.

By combining **advanced motion control algorithms** with robust safety mechanisms, STSPIN drivers help designers overcome key challenges in humanoid robotics: achieving precise actuation, maintaining energy efficiency, and ensuring operational robustness under variable loads and harsh conditions.

Part number	Description	Vin min (V)	Vin max (V)	Rdson (Ω)	I out max (Arms)
STSPIN830	3-phase 3-shunt BLDC motor driver	7	45	0.5	1.5
STSPIN9P1	High current half-bridge DC motor driver	7	75	0.016	10
STSPIN958	Full bridge motor driver	5	58	0.4	5

Motor drivers with integrated MOSFETs: POWERSTEP01

The **POWERSTEP01** addresses a key challenge in humanoid robotics: achieving **precise, configurable motion control under high-voltage conditions**. Designed for demanding applications, it operates at voltages up to **85 V** and integrates an advanced microstepping controller with eight power MOSFETs featuring a low **16 mΩ RDS(ON)** for efficient power delivery.

Its **dual-mode capability** allows designers to select between:

- **Voltage mode** – delivers exceptionally smooth and silent motion for fluid joint movement
- **Current mode** – ensures accurate torque control and stability

This flexibility is critical for humanoid robots where **motion quality and energy efficiency must coexist**.

Beyond core driving functions, the POWERSTEP01 includes:

- Fully customizable motion profiles for acceleration, deceleration, and speed
- Integrated positioning calculations
- **Sensorless stall detection**
- Real-time diagnostics and user-configurable failure protections

These capabilities enable **robust operation and long-term reliability**, even under variable loads and harsh conditions.

Part number	Description	Vin min (V)	Vin max (V)	Rdson (Ω)	I out max (Arms)
powerSTEP01	System-in-package integrating microstepping controller and 10 A power MOSFETs	7.5	85	0.016	10

Motor drivers with integrated MCU: STSPIN32G4

The STSPIN32G4 is an extremely integrated and flexible motor controller for driving **3-phase brushless motors**, helping designers implement the most suitable driving mode while reducing PCB area and overall bill of materials. In humanoid robots, this level of integration supports compact designs and efficient actuator control.

It embeds:

- **A triple half-bridge gate driver** able to drive power MOSFETs with **1 A sink/source current**
- **Three bootstrap diodes** for simplified design

The high- and low-side switches of the same half-bridge cannot be simultaneously driven high thanks to an **integrated interlocking function**. Additionally, **hardware VDS monitoring circuitry** constantly checks each of the six external MOSFETs and switches off all gate driver outputs if an overvoltage is detected.

An internal **high-precision low-drop LDO regulator** generates the **3.3 V supply (VREG3V3)** from the REGIN input voltage. This output powers both the gate driver logic and the microcontroller, and is protected against **short-circuit, overload**, and **undervoltage conditions**.

The integrated MCU **(STM32G431VBx3)** is based on the **32-bit Arm® Cortex®-M4 core**, operating up to **170 MHz**, and features:

- Single-precision FPU
- A full set of DSP instructions
- Memory protection unit (MPU) for enhanced security

Finally, with an external three-phase driver (such as **STDRIVE101**), the STSPIN32G4 can drive **two independent 3-phase BLDC motors**, offering BOM savings and application optimization—an advantage for humanoid robots requiring multiple coordinated joints.

Part number	Description	Vin min (V)	Vin max (V)
STSPIN32G4	Advanced BLDC controller with embedded STM32 MCU	5.5	75

STDRIVE three-phase bridge gate drivers

ST three-phase STDRIVE integrates all the required **gate drivers for three-phase motor applications** into a single component, providing a high level of integration that simplifies design and reduces development costs. This integration also helps ensure consistent **propagation delays**, which is critical for synchronized switching in power applications and beneficial for humanoid robots where precise timing across multiple actuators is essential.

Part number	Channel #	Voltage max (V)	Output current max (A)	Supply voltage c (V) max	TTL/CMOS logic inputs (V)	Propagation delay (ns)	Package
STDRIVE101	6	75	0.6	15	3.3, 5	120	QFN4x4 24 leads
STDRIVE131		52	2.2			400	TQFP7x7 48 leads

Power MOSFETs - STripFET F7

STripFET F7 MOSFETs deliver **very low on-resistance** across 40 V, 60 V, 80 V, and 100 V devices to minimize conduction losses. They combine this with **minimal capacitances and gate charge**, ensuring efficient switching and reduced energy waste.

To further enhance performance, the family features **optimized intrinsic capacitance ratios (Crss/Ciss)** to limit EMI effects, along with **high current capability** and **extremely low thermal resistance** for improved heat dissipation.

These characteristics allow designers to meet stringent power and efficiency targets while reducing equipment size and cost. In practice, this means fewer devices and more compact packages.

Key benefits include:

- Low on-resistance for reduced conduction losses
- Optimized capacitance ratios for EMI mitigation
- High current handling and superior thermal performance

Such features are particularly relevant in **humanoid robots**, where compact and efficient power stages are essential for driving multiple actuators reliably under demanding conditions.

VDSS	Part number	Marketing status	Package	$R_{DS(on)}$ (@VGS = 10 V) max (Ω)	Qg typ (nC)
100	STX310N10F7	Active	TO-220/H²PAK-2/H²PAK-6	0.0023	180
	STX150N10F7		TO-220/TO-220FP/H²PAK-2/I²PAK	0.0039	117
	STL110N10F7		PowerFLAT 5x6	0.006	72
	STX100N10F7		TO220/D²PAK/DPAK/TO-220FP	0.008	61
	STL90N10F7		PowerFLAT 5x6	0.008	45
	STX80N10F7		DPAK/TO-220FP	0.0095	45
	STL8N10F7		PowerFLAT 3.3x3.3	0.02	25
80	STX270N8F7		TO-220/H²PAK-2/H²PAK-6	0.021	193
	STX170N8F7		TO-220/H²PAK-2	0.0037	120
	STX140N8F7		TO-220/TO-220FP/H²PAK-2	0.004	96
	STL130N8F7		PowerFLAT 5x6	0.0036	96
60	STL220N6F7		PowerFLAT 5x6	0.0014	100
	STP220N6F7		TO-220	0.0023	100
	STL140N6F7		PowerFLAT 5x6	0.0028	55
	STX140N6F7		TO-220/H²PAK	0.0032	55
	STL130N6F7		PowerFLAT 5x6	0.0035	42
	STX130N6F7		TO-220/D²PAK/DPAK	0.005	42

PowerGaN transistor

ST e-mode PowerGaN 100 V transistors, offer extremely low conduction losses, high current capability, and ultrafast switching operation. These features enable high power density and unbeatable efficiency performances.

Part Number	Package	Grade	VDSS nom (V)	$R_{DS(on)}$ (mΩ) max	Drain Current (Dc) (A) max	P_{TOT} (W) max	Q_g (nC) typ	Technology
SGT1D5R10MEA	EN-FCLGA 5x6 mm	Industrial	100	1.5	474	658	19	e-mode GaN
SGT3D5R10MEB	EN-FCLGA 3.3x3.3 mm			3.5	201	255	7.6	

Note: ES available MP end Q2 2026

CURRENT SENSING

A **current sense amplifier** is a differential amplifier that provides an analog output voltage proportional to the current flowing into a load through its input.

In humanoid robots, current sensing solutions add safety and protection by preventing overheating and detecting short-circuits in high-power actuators. They also provide real-time feedback for **torque control** and adaptive motion.

Current sensing is essential for **energy metering**, enabling accurate power monitoring to optimize battery usage and ensure reliable operation in complex robotic systems.

Part number	Package	Grade	Supply voltage (V) min	Supply voltage (V) max	Common mode input voltage (V) min	Common mode input voltage (V) max	Bandwidth (kHz) (@ -3dB) typ	Current sensing (bidirectional)
TSC1801	SOT23-6	Automotive	2.0	5.5	0.5	3.5	2100	Yes
TSC240	SO-8, TSSOP-8	Automotive	2.7	5.5	-4	100	560	Yes
TSC202	MiniSO-8, SO-8	Automotive, Industrial		18	-16	80	200	No
TSC2020	MiniSO-8, SO-8, TSSOP-8L	Automotive, Industrial		5.5	-4	100	750	Yes
TSC2021	MiniSO-8, SO-8, TSSOP-8L	Automotive, Industrial		5.5	-4	100	750	Yes
TSC2022	MiniSO-8, SO-8, TSSOP-8L	Automotive, Industrial		5.5	-4	100	750	Yes
TSC210	QFN-10L, SC70-6	Automotive, Industrial		26	-0.3	26	25	Yes
TSC211	QFN-10L, SC70-6	Automotive, Industrial		26	-0.3	26	8	Yes
TSC212	QFN-10L, SC70-6	Automotive, Industrial		26	-0.3	26	6	Yes
TSC213	QFN-10L, SC70-6	Automotive, Industrial		26	-0.3	26	100	Yes
TSC214	QFN-10L, SC70-6	Automotive, Industrial		26	-0.3	26	40	Yes
TSC215	QFN-10L, SC70-6	Automotive, Industrial		26	-0.3	26	60	Yes

OPERATIONAL AMPLIFIER AND COMPARATOR

In humanoid robot applications, precision sensing, low power consumption, and high-speed signal conditioning are critical for enabling accurate motion control and real-time decision-making. STMicroelectronics offers a portfolio of operational amplifiers and comparators well-suited for these demands. Devices such as the TSZ901 and TSB192 provide ultra-low offset and high accuracy, enabling efficient operation in battery-powered robotic subsystems. The TSV794 quad high speed Opamp is ideal for processing low side current sensing to control torque and speed in motor application. Meanwhile, the TS3121 comparator delivers fast response and reliable threshold detection, essential for safety monitoring and event triggering. Together, these components enable optimized analog front-end design, enhancing precision, energy efficiency, and system reliability in advanced humanoid robotics.

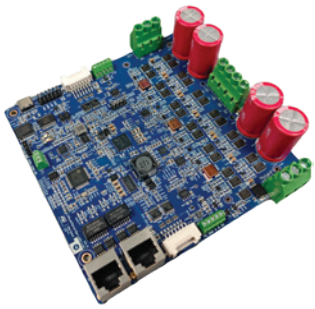
Part number	Package	Grade	Vcc (V)	Bandwidth (MHz)	Slew rate (V/us)	Vio (µV)	dVio/dT (µV/°C)	Device Type
TSV794	SO14, TSSOP14	Automotive, Industrial	2.2 to 5.5	50	30	200	5	Quad Op. Amp.
TSB192	SO8, Mini SO8		4 to 36	8	5	20	0.1	Single Op. Amp.
TSZ901	SOT23-5		2.5 to 5.5	10	6	5	0.03	Single Op. Amp.
TS3121P	SC70-5, SOT23-5		1.7 to 5.5	-	-	6000	20	Open Drain Comparator with POR

TURNKEY SOLUTIONS FOR JOINT MOTOR CONTROL

STEVAL-ETH001V1 (based on STM32F767ZI, STDRIVE101)

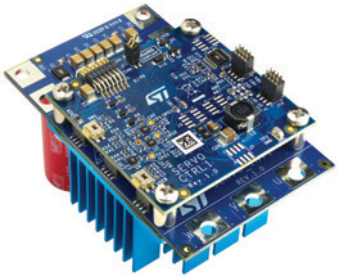
- 700 W/48 V servo drive
- Position control with FOC algorithm
- Hall sensor interface
- RTE - EtherCAT stack by Hilscher
- RS-485 physical layer

STEVAL-DUOSRV1CB (based on STSPIN32G4, STDRIVE101, STL90N10F7)



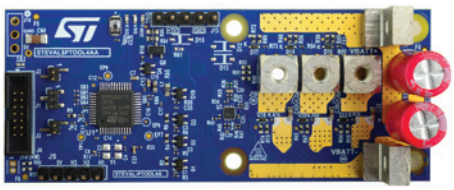
- 1 kW dual motor solution/48 V servo drive
- Position control with FOC algorithm
- Hall sensor interface
- RTE communication supporting CoE stack
- CAN physical layer

EVL-SERVO1 (based on STSPIN32G4, STL160N10F8)



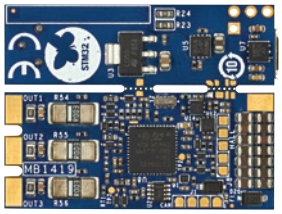
- Optimized for 48 V
- Up to 3 kW active cooling 2 kW with passive cooling
- External regenerative braking resistor
- Speed and position feedback supporting hall sensors and incremental/absolute encoder
- CAN bus communication

STEVAL-PTOOL4A (based on STM32G4, STDRIVE101, STL220N10F7)



- Up to 28 V motor drive board supporting FOC algorithm (up to 48 V with L7987L)
- ZeST firmware for torque maximization at very low speed
- Max current 18 A
- Very low standby power consumption
- CAN bus communication

B-G431B-ESC1 (LP)



- 24 V motor drive board supporting FOC algorithm
- 3-phase motor driving
- Max current with air forced cooling 40 A
- Compact form factor

SOFTWARE AND FIRMWARE

BLDC motors

STM32 MC SDK (X-CUBE-MCSDK) provides a comprehensive firmware package for motor control, including a **permanent-magnet synchronous motor (PMSM) library** and the **STM32 Motor Control Workbench** for parameter configuration through a graphical interface.

The Workbench software for PC simplifies firmware setup by allowing designers to generate a project file and initialize the library according to application needs. Variables within the control algorithm can be monitored and adjusted in real time, which is particularly useful for humanoid robots where dynamic load conditions and precise torque control are critical.

In practice, this capability supports:

- **Adaptive motion tuning** for joints under varying mechanical stress
- Real-time parameter adjustments to maintain stability during complex movements
- Efficient integration of field-oriented control (FOC) strategies for smooth actuator performance

By reducing design effort and enabling real-time feedback, STM32 MC SDK helps address key challenges in humanoid robotics, such as balancing energy efficiency with motion precision across multiple actuators.

X-CUBE-MCSDK
Motor control software development kit (PMSM FOC) BLDC/6-step

STM32 motor profiler	STM32 motor pilot	STM32 motor control workbench	Motor control firmware library
Identify the characteristics of PMSM and BLDC motors	Monitoring tool for STM32 motor-control applications	Configure the FOC firmware library parameters, thanks to its GUI	Based on STM32Cube HAL and LL

State-of-the-art algorithms

HSO	STM32 ZeST
	Contact ST sales

STM32CUBE

Stepper and DC brushed motors

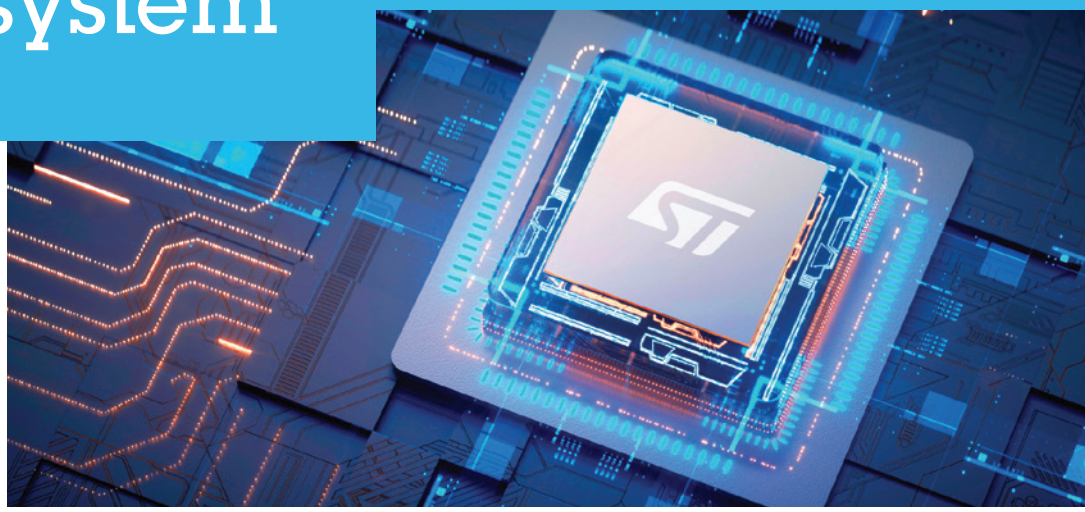
STSPIN Studio is an easy-to-use software tool for evaluating **brushed DC** and **stepper motors** with the STSPIN family of devices. It enables control of multiple **stepper** and **brush DC motor driver evaluation boards**, simplifying early-stage development.

In the context of **humanoid robotics**, designers often need to:

- **Validate motor performance** under different load conditions before committing to hardware integration
- **Experiment with motion profiles** for joints such as elbows or wrists, where smoothness and torque control are critical
- **Optimize energy efficiency** by tuning parameters that affect battery life and thermal behavior

By providing a **software-driven evaluation environment**, STSPIN Studio helps engineers **reduce prototyping complexity** and **accelerate algorithm development** for robotic systems.

Body Main Processing unit subsystem



Introduction

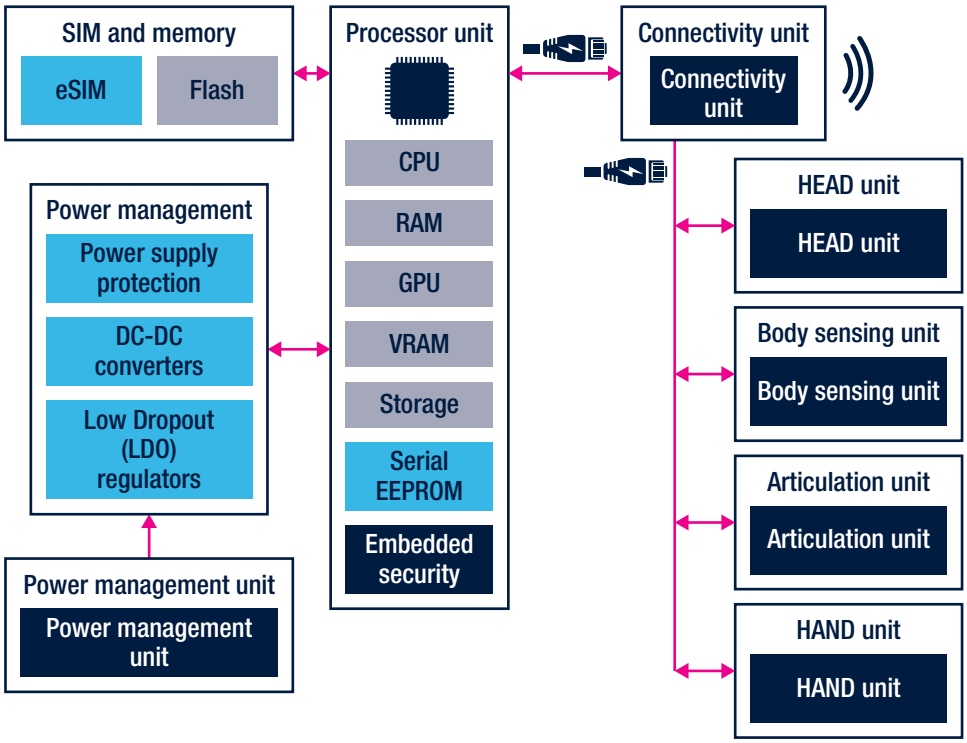
The main processing unit is the central control hub of a humanoid robot. It embeds a high-performance microprocessor, memories, secure elements, and embedded security to manage complex tasks such as motion planning, sensor fusion, and real-time decision-making.

In humanoid robotics, this unit is critical because it must:

- Coordinate multiple subsystems (vision, locomotion, manipulation) with low latency
- Handle AI algorithms for perception and adaptive control
- Ensure data integrity and cybersecurity, especially in collaborative environments
- Support high-speed memory access for large datasets from sensors and actuators

ST offers a wide range of products covering memories, secure elements, and embedded security, enabling designers to build systems that are both powerful and safe for advanced robotic applications.

SUBSYSTEM BLOCK DIAGRAM



MEMORIES

EEPROM memories are used inside the humanoid storing any kind related to settings, history data, or post processing results. A detailed list of part number and related features are reported in the **backbone paragraph**.

EMBEDDED SECURITY

Embedded security is an important features in this kind of application and can be distributed inside the robot in different blocks. Details information about the ST offer are reported in the **backbone paragraph**.

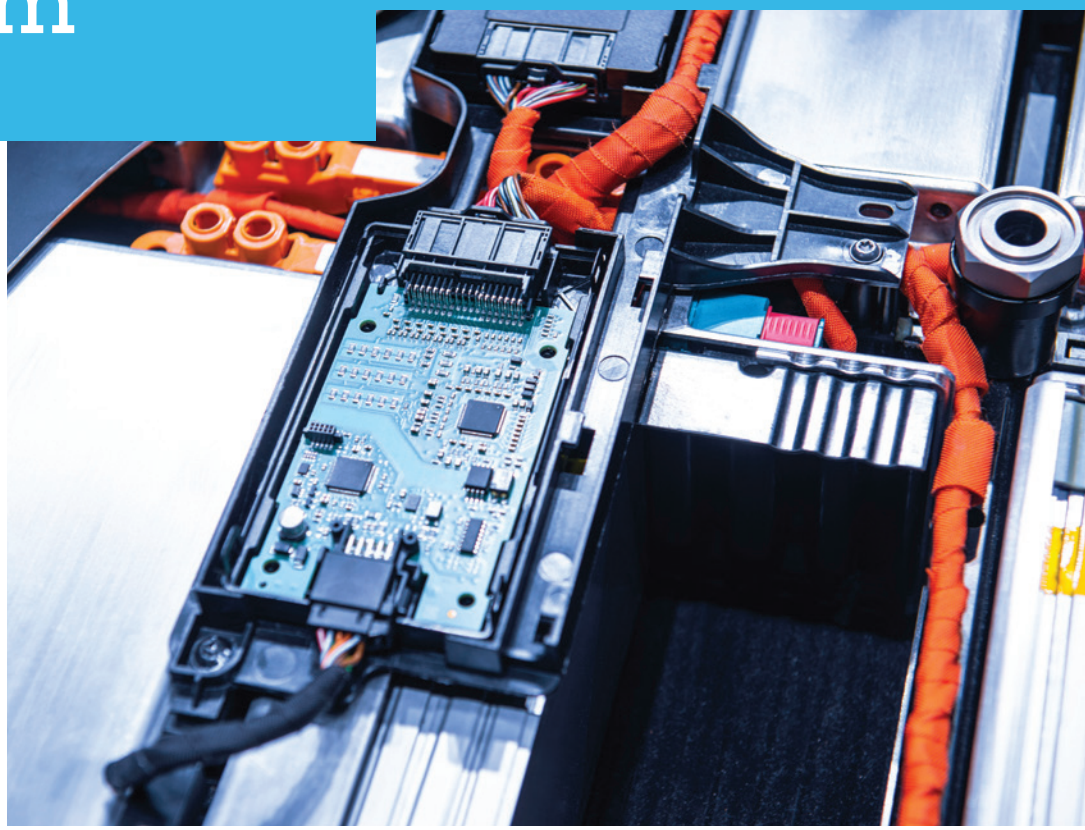
Power management unit subsystem

Introduction

Through technology, integration, and reliability, ST covers a wide range of solutions for humanoid robots. These include:

- Devices for voltage conversion to adapt battery power to different subsystems.
- Regulators for voltage stabilization, especially for low-voltage logic circuits.
- Sensing circuits for monitoring current, temperature, and position.
- Power conversion components for efficient motor drive systems.
- Battery management system devices to ensure safe charging, discharging, and energy metering.

These building blocks are essential for humanoid robots, where power efficiency, system safety, and precise control must coexist in a compact and reliable architecture.



SUBSYSTEM BLOCK DIAGRAM

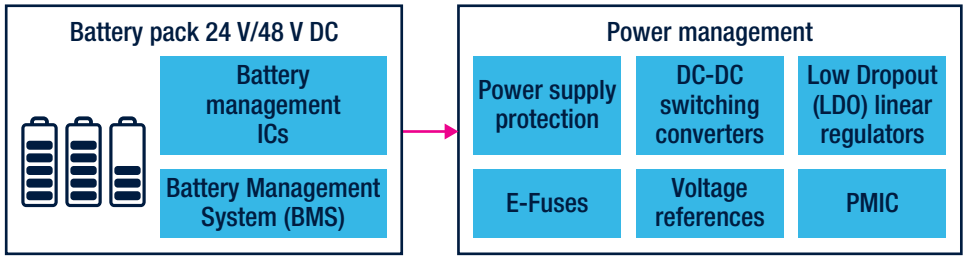
In humanoid robots, **power management** is a critical subsystem that ensures stable operation across multiple functional domains. The architecture typically involves:

- **A centralized main unit** located near the battery pack, responsible for high-level power distribution and monitoring
- Several **decentralized power management modules** positioned throughout the robot. These modules handle localized tasks such as low-voltage reference generation for sensors, actuators, and control boards

This distributed approach minimizes voltage drops, reduces wiring complexity, and enhances fault tolerance—key considerations in systems where mobility and reliability are paramount.

Some practical considerations include:

- Thermal management becomes essential when multiple regulators operate in confined spaces
- Isolation between high-power and low-power domains helps prevent noise interference in sensitive control circuits
- Modular design allows easier maintenance and scalability for future upgrades



SWITCHING CONVERTER AND VOLTAGE REGULATOR ICs

Low drop voltage regulator

LDO regulators are a subset of linear voltage regulators designed to operate with a very low input-to-output voltage differential—known as the **dropout voltage**. This characteristic is particularly valuable in humanoid robots, where space and thermal constraints demand efficient power conversion.

Key advantages:

- **Reduced heat dissipation:** Lower dropout voltage minimizes power loss as heat, improving thermal management.
- **High conversion efficiency:** Especially when the input and output voltages are close
- **Design simplicity:** Requires few external components, making integration straightforward
- **Cost-effectiveness:** Ideal for low-current applications (typically below a few amps)

Best use cases:

- When the output voltage is near the input voltage, avoiding unnecessary energy waste
- For localized low-voltage reference generation in distributed power management systems within robotic limbs or sensor clusters

While LDOs excel in these scenarios, they are less suitable for high-current loads or large voltage differentials, where switching regulators may offer better efficiency.

Part number	Package	Grade	DC input voltage (V) max	Output voltage (V) nom	Output current (A) nom	Adjustable regulated output voltage	Dropout voltage (V) nom
LDLN025	Flip-Chip4, DFN4 1x1, SOT23-5L	Industrial	5.5	1.2 to 5	0.25	No	0.25
LDH40MRY	DFN 2x2 6L, SOT23 5L, SOT23 5L, DFN 6L	Automotive	40	1.2 to 22	0.2	Yes	0.7

DC-DC converter

In humanoid robots, the power management unit (PMU) is a critical component that integrates DC-DC converters to optimize energy usage. These converters are essential for maintaining stable voltage levels across various subsystems, including motor drivers, communication modules, and advanced processing units. By leveraging high-efficiency DC-DC converters, the PMU ensures that the robot operates reliably under varying load conditions, extending battery life and enhancing overall performance. Furthermore, the compact design of these converters allows for seamless integration into the limited space available in humanoid robots, while their high switching frequencies reduce electromagnetic interference (EMI), ensuring smooth operation of sensitive electronic components.

The ST portfolio includes highly specialized products designed to address diverse market requirements and power management needs. These include high-voltage technology with exceptional reliability and robustness for industrial and automotive applications, as well as compactness and high efficiency tailored for consumer applications.

Part number	Package	Grade	Input voltage (V) min	Input voltage (V) max	Regulated output voltage (V) min	Regulated output voltage (V) max	Output current (A) max	Synchronous rectification	Regulator switching frequency (kHz) typ
L3751	QFN 3.5x4.5x1.0 20L PITCH 0.50	Industrial	6	75	0.8	60	-	Yes	400
DCP0606Y	POA FCQFN 2x3x0.9 11L	Automotive	-0.3	6.5	-	-	6	-	-
DCP360x	SOT23-6L	Industrial	3.3	36	0.85	-	3	Yes	500, 1000

Multioutput controller ICs

Efficient power distribution is a fundamental requirement in humanoid robotics, where compact design, thermal constraints, and dynamic load conditions impose stringent demands on system architecture. Multioutput power management integrated circuits (PMICs) address these challenges by reducing component count and optimizing overall system size while sustaining high performance.

ST's multioutput PMIC solutions employ advanced power technologies to deliver **high-efficiency and cost-effective architectures**. These devices integrate low-dropout regulators (LDOs) with high-efficiency DC-DC converters, ensuring superior transient response and precise output voltage regulation across a broad range of operating conditions. Such characteristics are essential for robotic platforms incorporating heterogeneous subsystems, including vision processing, motion control, and sensor arrays.

Notably, the **STPMIC07M, STPMIC06, and STPMIC02** families are designed to support storage and embedded applications within robotics systems. They incorporate integrated protection mechanisms, multiple regulators, and versatile interfaces, thereby facilitating robust and scalable power delivery for complex designs.

Key engineering considerations include:

- **Component minimization:** Consolidating multiple power rails reduces PCB complexity and potential failure points
- **Thermal efficiency:** High conversion efficiency mitigates heat accumulation, critical for enclosed robotic assemblies
- **Design flexibility:** Multioutput configurations enable tailored voltage domains for diverse functional blocks

By adopting such PMIC architectures, designers can achieve compact, energy-efficient humanoid robots capable of sustained operation under variable and demanding workloads.

Part number	Package	Number of output nom	Input voltage (V) min	Input voltage (V) max	Output current-max (A) nom	Regulated output voltage (V) max	Efficiency (%) nom	Grade	Synchronous rectification
STPMIC2L	VFQFPN40L 5x5x1	10	2.8	5.5	2	3.3	80	Industrial	Yes
STPMIC1	WFQFN 44L 5x6x0.8 PITCH 0.4	14	2.8	5.5	2	3.9	95		Yes
STPMIC1L	VFQFPN 28 4x4x1.0	-	2.8	5.5	-	-	-		-
STPMIC25	VQFN6.5x6.5x0.9 56L PITCH 0.40	-	2.8	5.5	-	-	95		Yes

HALF-BRIDGE GaN DRIVER

The **STDRIVE GaN gate driver family** comprises half-bridge gate drivers specifically designed for enhancement-mode GaN FETs or N-channel power MOSFETs. These devices enable efficient and reliable operation in high-performance power conversion systems.

The **high-side section** is engineered to withstand voltages up to **600 V**, making it suitable for applications with bus voltages up to **500 V**. Their architecture supports driving high-speed GaN and Si FETs through features such as:

- **High current capability** for rapid switching
- **Short propagation delay**, critical for minimizing timing losses
- Operation with supply voltages as low as **5 V**, enhancing design flexibility

These drivers incorporate:

- **UVLO protection** on both high-side and low-side stages, preventing operation under low-efficiency or unsafe conditions
- **Interlocking functionality** to avoid cross-conduction between power switches
- **CMOS/TTL-compatible logic inputs** down to **3.3 V**, simplifying interfacing with microcontrollers and DSPs

STDRIVE devices are well-suited for advanced power electronics in robotics and other domains requiring compact, high-speed switching solutions.

Part number	Package	Supply voltage (VDD) (V) max	Protection option type nom	Power switches type (external)	Undervoltage lockout (V) (@ V_{CC} ON) nom	Undervoltage lockout (V) (@ V_{CC} OFF) nom	Grade
STDRIVEG210	QFN-18L	18	Undervoltage lockout, Interlocking function, Overtemperature	GaN	8.5	8	Industrial
STDRIVEG211			Comparator, Smart shutdown, Undervoltage lockout, Interlocking function, Overtemperature		10	9.5	

BATTERY MANAGEMENT

Battery management integrated circuits (ICs) ensure operational safety and extend the autonomy of battery-powered devices, including advanced robotic platforms. These solutions perform critical monitoring functions by providing accurate measurements of **voltage, current, and temperature**, to determine the precise state of charge for individual cells and battery packs.

Beyond energy optimization, battery management ICs incorporate **safety mechanisms** that disconnect power when temperature thresholds are exceeded during operation or charging. This prevents hazardous conditions such as thermal runaway and ensures compliance with stringent reliability standards.

Key functional aspects include:

- **State-of-charge accuracy** through precise sensing and calibration
- **Thermal protection** to safeguard cells under extreme conditions
- **Energy control** for balanced charging and discharging cycles

Such capabilities are indispensable in humanoid robotics, where uninterrupted power delivery and system integrity directly influence mobility, performance, and user safety.

Part number	General Description	Package	Operating temperature (°C) min	Operating temperature (°C) max	Supply voltage (VDD) (V) min	Supply voltage (VDD) (V) max
L99BM114	Multicell battery monitoring and balancing IC	TQFP 64 10x10x1.0	105	8.5	8	Industrial

PROTECTIONS

ESD protections

Incorporating ESD protection at strategic points such as sensor hubs, motor controllers, and AI compute boards is essential in humanoid robotics, where complex electronics operate in environments prone to static buildup. ST's ESD protection devices, compliant with **IEC 61000-4-2 standards**, provide a robust safeguard against electrostatic events that could disrupt system performance or damage sensitive components.

Originally tailored for automotive-grade reliability, these devices deliver characteristics that are equally critical for robotics. Low clamping voltage ensures efficient energy dissipation during ESD strikes, reducing stress on processors and sensors. Low leakage current helps maintain power integrity in low-power subsystems, while ultralow capacitance combined with ultrawide bandwidth preserves signal integrity for high-speed interfaces such as vision systems and communication buses.

Part number	General description	Package	Directionality	Breakdown voltage (V) min	Capacitance (pF) (@ 0V, I/O to GND) typ	IEC 61000-4-2 (kV) (contact discharge) min	Clamping voltage (V) (@ TLP 16A) typ
ESD051-1BF4	Automotive single line 5 V TVS in SOD323	SOD323	Uni-Directional	6.2	190	30	-
ESDA051-1JY	4 line ESD protection, 14.2 V VBR, in SOT666	SOT666	Bi-Directional	14.2	25	8	-
ESDA14V2BP6	Automotive dual-line 12 V TVS in SOT23-3L	SOT23-3L	Uni-Directional	14.2	90	30	-
ESDA14V2LY	Quad Transil™ array for ESD protection	SOT23-6L	Uni-Directional	14.2	100	30	-
ESDA14V2SC6	Automotive dual-line unidirectional 12 V ESD protection in SOT323	SOT323	Uni-Directional	14.2	125	30	17.5
ESDA18WY	Quad Transil™ array for ESD protection	SOT23-6L	Uni-Directional	19	80	30	-
ESDA19SC6	4 line ESD protection, 25 V VBR, in SOT666	SOT666	Bi-Directional	25	22	8	-
ESDA25-4BP6	Automotive dual-line 24 V TVS in SOT23-3L	SOT23-3L	Uni-Directional	25	50	30	-
ESDA37WY	Low clamping single line unidirectional ESD protection	ST0201	Uni-Directional	5.8	110	30	-
ESDAxxxWx	Automotive dual-line TVS in SOT23-3L for CAN bus (12 V system)	SOT23-3L	Bi-Directional	25	25	30	-
ESDCAN01-2BLY	Automotive dual-line TVS in SOT323-3L for CAN bus (12 V system)	SOT323	Bi-Directional	28.5	3	30	-
ESDCAN02-2BWY	Automotive dual-line TVS in SOT323-3L for CAN bus (24 V system)	SOT323	Bi-Directional	39	3	30	-
ESDCAN05-2BWY	Automotive dual-line TVS in SOT23-3L for CAN bus (24 V system)	SOT-23	Bi-Directional	38	13	30	-

eFuses

eFuses provide a fast and intelligent response to faults by clamping the output voltage or limiting the current, rather than melting a conductor as in conventional fuses. This approach protects both the load and the supply from damage and prevents false triggering during transient conditions. In DC bus applications, eFuses minimize voltage drops caused by faulty loads, preventing undervoltage from affecting other devices on the same bus. Because eFuses do not destroy their pass element, they can be reset by cycling the supply power or through auto-retry, which maximizes equipment uptime and reduces maintenance costs. eFuses also support hot-plug and hot-swap operations by controlling the output voltage ramp-up, which limits inrush current and protects the power supply when multiple loads are connected. Additionally, eFuses offer flexible configuration options, allowing users to set current limits, startup times, undervoltage lockout, output clamp levels, and operating modes to suit specific application requirements.

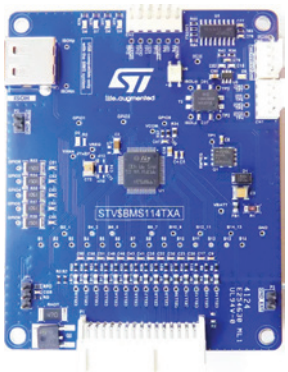
Part Number	Package	Grade	Vcc (V)	Operating voltage (V)	Diagnostic features	Peripheral interfaces
STEF12H60M	QFN 5x5	Industrial	5 to 18	12	Programmable soft-start, OC, OT, Very fast SC protection	No
STEF12H60G						
VNFD1248	QFN 5x5x0.9	Automotive	6 to 70	12/24/48	2t curve, OV, UV, SC,OT, Emergency Stop, Limp-home, STBY-On for low cunsumption mode	SPI
STEF4848H28*	QFN42L 7x7 mm	Automotive	9 to 80	Industrial	Overcurrent, Thermal protection, Temperature monitoring	-

Note: * Product in preview on: www.st.com

Configuration	Product	Channels	Package	Current limitation (A)	Shutdown peak current (A)	On-resistance per channel (mΩ)	Operating voltage (V)
Gate controller	**VNF1048F**	1	QFN 5x5	Internally limited	-	External MOSFET	6 to 70
	VNF1248F	1		Internally limited	-	External MOSFET	6 to 70
Integrated solution	**VNF9D5F**	2	QFN 6x6	75.0	-	5.9	4 to 28
	VNF9Q20F	4		34.5	-	21.5	4 to 28
	VNF9D1M2Q	2	PQFN 7x8.5	-	145	1.2	4 to 28
	VNF9D1M5Q	2		-	120	1.5	4 to 28
	VNF9D3Q	2		-	70.0	3.0	4 to 28

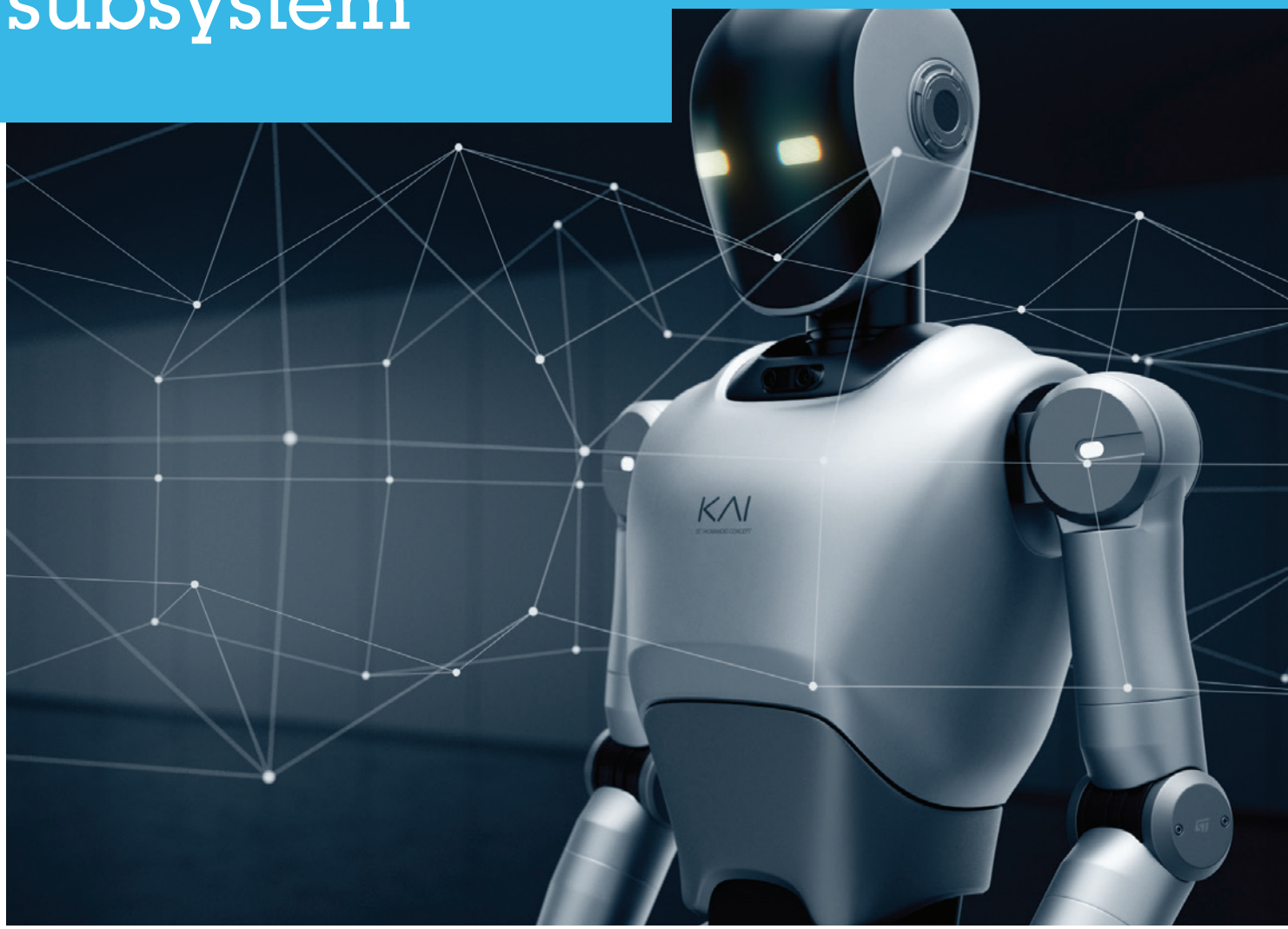
TURNKEY SOLUTIONS

STEVAL-BMS114TX (Enabling products L99BM114 battery monitoring, L99BM1T SPI transceiver)



- Ability to manage 4 to 14 battery cells
- Voltage monitoring single cell and of the entire battery node
- Current sensing of the entire battery node
- Cell and battery node status check
- Communication with remote MCU for SOH and SoC
- Passive balancing

Connectivity unit subsystem

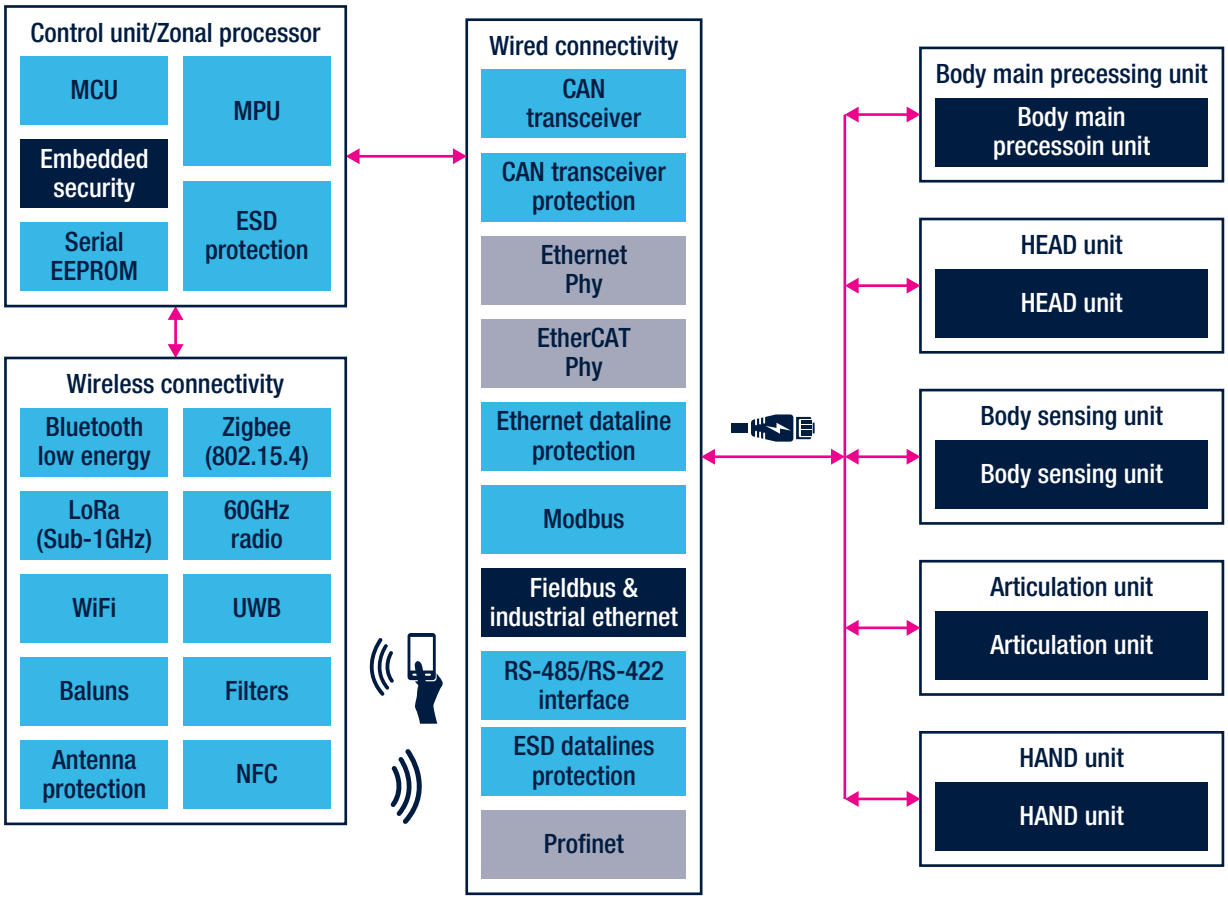


Introduction

Connectivity is fundamental in humanoid robotics, enabling seamless communication between sensors, actuators, and control units. ST provides comprehensive solutions for both wired and wireless connectivity through dedicated ICs and embedded modules.

These connectivity options allow humanoid robots to maintain efficient internal communication while supporting external interfaces for control, data exchange, and system updates, ensuring flexibility and scalability in advanced robotic architectures.

SUBSYSTEM BLOCK DIAGRAM



CONTROL UNIT AND ZONAL PROCESSOR

This block identifies delocalized control unit embedding microcontrollers, microprocessors, memories and other devices.
MPUs, memories and embedded security will be deeply described with referenced part number in the **backbone paragraph**.

WIRED CONNECTIVITY

ST supports wired connectivity in system solutions by addressing both hardware and software aspects.

On the hardware side, offers microcontrollers and transceivers designed for robust industrial communication and high-speed data transfer. For the Ethernet physical layer, ST collaborates with partners that develop hardware supporting EtherCAT.

On the software side, ST and its partners provide support for EtherCAT, Functional Safety over EtherCAT, and CANopen protocols. These solutions enable reliable and safe industrial automation.

For more details on partner program visit ST web site to the link **https://www.st.com/en/partner-products-and-services.html**

RS-485

The ST4E1216, ST4E1240, and STR485 series are low-power differential line transceivers for modern RS-485 applications in half-duplex mode. Compatible with 3.3 V and 5 V power supplies, and with a 1.8 V capability for I/Os for the STR485 series, these transceivers offer robust performance, high data rates, and exceptional ESD protection.They are perfect for multipoint applications over extended cable runs, ensuring reliable data transmission even in complex environments.

Part number	Package	Number of output nom	Input voltage (V) min	Synchronous rectification
ST4E1240	SO8, DFN8	3 to 5.5	40	Half duplex
ST4E1216	SO8		16	
ST4E1650F	DFN10	3 to 3.6	50	Full duplex
ST4E165xF	SO14			
ST4E1650	SO8, DFN8, MSOP8	3 to 5.5		Half duplex

WIRELESS CONNECTIVITY

ST addresses wireless connectivity through dedicated product and embedded solutions for, NFC, Bluetooth® Low Energy (LE), and Wi-Fi. NFC is supported by discrete tags as well as dynamic tags and readers connected to an STM32 controller for applications such as access control, accessory recognition, and parameter setting.

BLE functionality is available via dedicated modules as well as embedded implementations within microcontrollers, facilitating low-power, short-range communication for peripheral devices. Wi-Fi connectivity is supported through specialized modules, enabling high-bandwidth data transfer for applications such as remote monitoring, diagnostics, and cloud integration.

ST25 NFC tags & readers

NFC provides a simple, zero power way to identify users, accessories, and modules anywhere on the humanoid platform. The ST25 family of NFC tags, dynamic tags, and readers give humanoid robots an intuitive contactless interface for communication, accessory recognition, and parameter setting compatible with any NFC-enabled smartphone or dedicated NFC reader.

- **Access management for doors, panels, tool lockers, or docking stations:** store credentials in ST25 tags that can be checked by ST25 readers connected to an STM32 controller, granting temporary or role-based access to maintenance staff or operators.
- **Access recognition and automatic configuration:** reduce set-up time by identifying each attachment and automatically load matching parameters such as kinematic limits, safety thresholds, or communication settings using accessory recognition based on compact ST25 tags and dynamic tags.
- **Contactless parameter setting and in-box configuration:** personalize control boards, adjust configuration registers, or upload new calibration data without unboxing units or powering the system with the fast-transfer mode, low-power operation, and energy-harvesting capability of ST25 dynamic tags.

Part number	Package	Synchronous rectification
ST25TN01K	NFC Forum Type 2 tag IC	ISO14443A
ST25TV02KC	NFC Type 5/RFID tag IC	ISO15693
ST25DV64KC	Dynamic NFC/RFID tag IC	ISO15693
ST25R200	General-purpose NFC reader	ISO14443A/B, ISO15693
ST25RN300	NCI reader/NFC controller	ISO14443A/B, ISO15693, FeliCa

The ST25 portfolio includes a comprehensive ecosystem—including STM32 based discovery kits, ready to use Nucleo shields, software tools, and mobile apps—that makes it straightforward to add NFC to any robot connectivity subsystem.

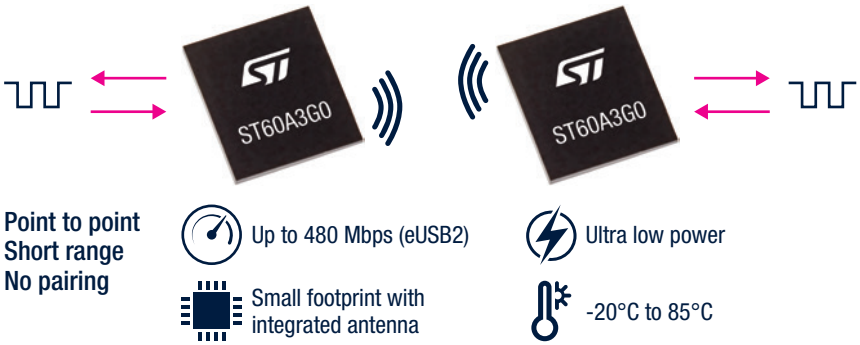
High-speed 60 GHz RF transceiver

The **ST60 series** provides advanced contactless communication solutions operating in the **60 GHz V-Band**, delivering high-speed wireless data transfer for compact and power-sensitive applications. These transceivers enable connectivity up to **480 Mbps** in standard configurations and support **peak transfer rates of 6.25 Gbps**, offering best-in-class performance with exceptionally low power consumption.

The **ST60A3G1** variant is designed for mobile and embedded systems, featuring:

- **Miniature form factor** for space-constrained designs
- **Optimized bill of materials (BOM)** to reduce system complexity and cost
- **Low-power operation**, critical for battery-powered devices
- Compliance with **eUSB2, UART**, and **I²C** protocols, ensuring versatile integration across diverse architectures

Its innovative architecture combines high-speed RF performance with ease of implementation, enabling designers to achieve efficient, compact solutions without compromising data throughput or reliability.



TYPICAL APPLICATIONS

- Contactless test factory automation and aftersales services
- Life proof holeless personal devices
- Contactless accessories
- Contactless personal equipment docking hub and data transfer

Part number	Package	Operating temperature (°C) max	Operating temperature (°C) min
ST60A2	VFBGA 25 2.2x2.2x0.8 P 0.4 mm	104	-40

Low-power Wi-Fi 6 & Bluetooth LE combo coprocessor module

This all-in-one design reduces costs and enhances performance, making it an attractive choice for IoT edge devices requiring a single-chip solution. The **ST67W611M1** operates as an IoT connectivity transceiver, leaving the external host STM32 MCU to manage the application.

The ST67W611M1 integrates:

- A PCB antenna (version -B), an RF connector (version -U) for external antenna, or a version with a dedicated RF pin, typically to support multiantenna implementations with an external RF switch
- 4 MB NOR flash
- 40 MHz high-precision quartz for optimal RF performance
- SMPS functionality and associated bill of material (BOM)
- All discrete components needed to reduce the overall board BOM
- Data interface through SPI
- 32,768 Hz internal oscillator. For low-power use cases, two pins are provided to use a 32,768 Hz quartz. One pin can also be used to receive an accurate 32,768 Hz from the host processor

This combination of integrated components and flexible configurations makes the ST67W611M1 a robust solution for IoT systems where efficiency, reliability, and space optimization are critical.

Part number	Wi-Fi version	Wireless interface	Antenna	Operating voltage (V) max	Output power (dBm) max	At frequency range (GHz)	Communication protocol
ST67W611M1	6	Bluetooth LE, Wi-Fi	Integrated, UFL Connector	3.63	20	2.4-2.5	802.11 b/g/n/ax, Bluetooth LE, TCP/IP

Bluetooth Low Energy 2.4 GHz connectivity

The **Bluetooth Low Energy (BLE) specification**, with its timing constraints, supports **low-power RF connectivity** for wireless devices, which is relevant in humanoid robotics where efficient energy use is important for extended operation.

The **2.4 GHz proprietary radio examples**, provided in software development kits and based on the **BlueNRG SoC radio low-level driver**, can be used as reference for applications requiring accurate communication and fast data transfer within robotic systems.

Part Number	Package	Operating voltage (V) max	Internal flash size (kByte) nom	Internal RAM size (kByte) nom	RX sensitivity (dBm) typ	Output power (dBm) max
BlueNRG-1	VFQFPN 32 5x5x1.0 mm, VFQFPN 5x5x1.0 32L WET FLK, WLCSP MSL1	3.6	160	24	-88	8
BlueNRG-2	VFQFPN 32 5x5x1.0 mm, VFQFPN 48 6x6x0.9 mm, VFQFPN 5x5x1.0 32L WET FLK, VFQFPN 6x6x0.85 48L P0.4 WF, WLCSP MSL1		256	24	-88	8
BlueNRG-M2	BLUENRG-2 MODULE QFN, PCB ANT, BLUENRG-2 MODULE QFN, CHIP ANT		256	24	-85	7
BlueNRG-2N	VFQFPN 32 5x5x1.0 mm, VFQFPN 5x5x1.0 32L WET FLK, WLCSP MSL1		-	-	-88	8

Bluetooth LE application processors

ST offers a comprehensive range of **Bluetooth® Low Energy (LE) microcontrollers** designed to meet diverse application requirements:

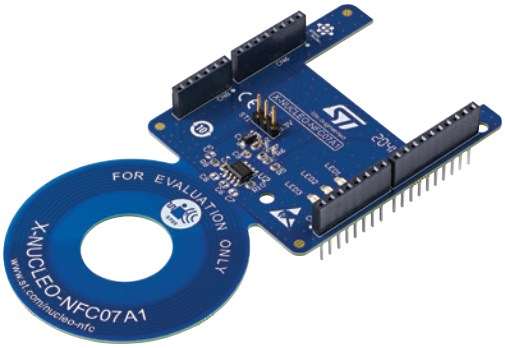
- Entry-level and cost-sensitive designs
  - **STM32WB0 series:** Tailored for basic connectivity and optimized for affordability
- High-performance and flexible solutions
  - **STM32WB and STM32WBA series:** Provide advanced processing capabilities and broad applicative flexibility

In addition to microcontrollers, ST's portfolio includes Bluetooth® LE application processors, featuring optimized network and application processors for modular designs, as well as all-in-one solutions that combine both functions in a single product for simplified integration. Multiple package options, from QFN32 to BGA121, are available to accommodate different footprint and feature set requirements.

Part Number	Package	Standby current (µA) typ	RX sensitivity (dBm) typ	Output power (dBm) max
STM32WB05KZ	VFQFPN 32 5x5x1.0 mm	0.64	-104	8
STM32WB05TZ	WLCSP MSL1	0.64	-104	8
STM32WB06CC	VFQFPN 48 6x6x0.9 mm, WLCSP MSL1	0.64	-104	8
STM32WB09KE	VFQFPN 32 5x5x1.0 mm	0.64	-104	8
STM32WB15CC	UFQFPN 48 7x7x0.55 mm, WLCSP 49 3.3x3.4x0.6 P 0.4 mm	0.6	-96	6
STM32WB30CE	UFQFPN 48 7x7x0.55 mm	0.7	-100	4
STM32WB35CE	UFQFPN 48 7x7x0.55 mm	0.6	-100	6
STM32WB50CG	UFQFPN 48 7x7x0.55 mm	0.7	-100	4
STM32WB55CC	UFQFPN 48 7x7x0.55 mm	0.6	-100	6
STM32WB55CG	UFQFPN 48 7x7x0.55 mm	0.6	-100	6
STM32WB55VG	UFBGA 129 7x7x0.6 P 0.5 mm, WLCSP 100 4.4x4.4x0.6 P 0.4 mm	0.6	-100	6
STM32WB55VY	WLCSP 100 4.4x4.4x0.6 P 0.4 mm	0.6	-100	6
STM32WB5MMG	SIP LGA 86 7.3x11x1.342 mm	0.25	-100	6
STM32WBA50KG	UFQFPN 32 5x5x0.55 mm	-	-96	10
STM32WBA55CE	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA55CG	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA55HG	WLCSP 41 3x2.8x0.47 P 0.40 mm	-	-96	10
STM32WBA5MMG	SIP LGA 76 8x12.5x1.372 mm	-	-96	10
STM32WBA62CG	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA62MG	WLCSP 88 3.8x3.5x0.47 P 0.35 mm	-	-96	10
STM32WBA62MI	WLCSP 88 3.8x3.5x0.47 P 0.35 mm	-	-96	10
STM32WBA63CG	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA63CI	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA64CG	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA64CI	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA65CG	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA65CI	UFQFPN 48 7x7x0.55 mm	-	-96	10
STM32WBA65MI	WLCSP 88 3.8x3.5x0.47 P 0.35 mm	-	-96	10
STM32WBA65RG	VFQFPN 68 8x8x1.0 mm	-	-96	10

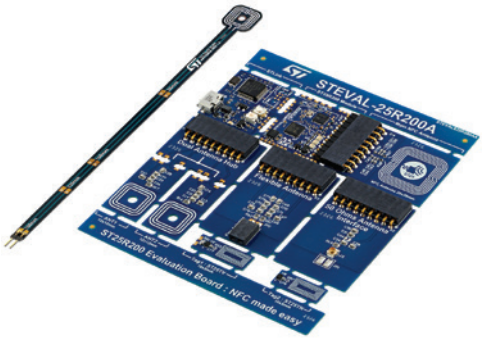
TURNKEY SOLUTIONS

X-NUCLEO-NFC07A1



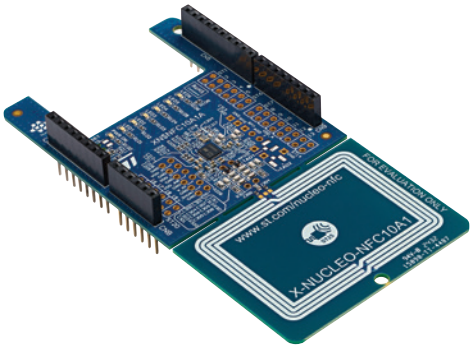
STM32 Nucleo expansion board based on ST25DV64KC.

STEVAL-25R200SA



ST25R200 discovery kit,Five 13.56 MHz inductive antennas etched on the PCB and associated tuning circuits.

X-NUCLEO-NFC10A1



STM32 Nucleo expansion board based on ST25R200.
ISO/IEC 14443 type A/B and ISO/IEC 15693 RF communication protocols.

Head unit subsystem

Introduction

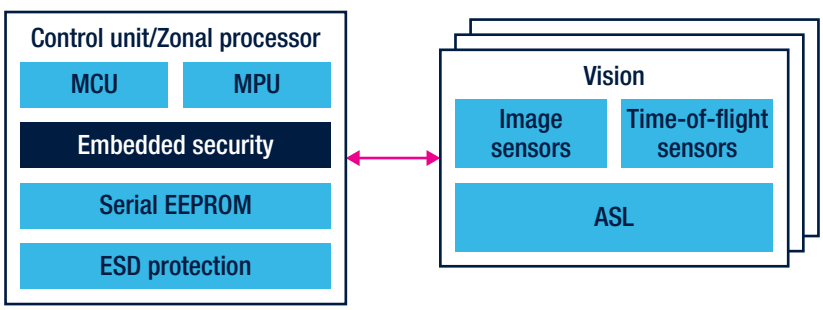
The integration of vision architecture and artificial intelligence (AI) represents a major advancement in humanoid robotics. Vision systems allow robots to perceive and interpret their surroundings through advanced image processing and sensor fusion techniques. When combined with AI, these systems enable real-time analysis of visual data, object recognition, and decision-making, which significantly improves the ability of humanoid robots to interact with dynamic environments.

This combination enhances autonomy and expands practical applications in areas such as healthcare, where robots assist with patient monitoring and rehabilitation; manufacturing, where they support collaborative assembly and inspection; and customer service, where they provide interactive experiences in retail and hospitality.

Vision systems paired with AI algorithms enable key functionalities such as object recognition and classification, gesture and face recognition, and navigation with obstacle avoidance. These capabilities depend on continuous data acquisition and interpretation to adapt to real-world conditions.

To achieve robust perception, humanoid robots integrate multiple sensor technologies and powerful data processing. Image sensors capture high-speed images without motion blur, while 3D depth sensors provide spatial awareness and accurate distance measurement. Proximity sensors help prevent collisions, and ambient light sensors maintain performance under varying lighting conditions, STM32N6 microcontroller to collect and process acquired data using AI algorithm to build human like sense in humanoid. These components are distributed across different parts of the robot—head, torso, and limbs—to ensure comprehensive environmental awareness.

SUBSYSTEM BLOCK DIAGRAM



ALS AND ToF

Ambient Light Sensors (ALS) are essential for maintaining consistent vision performance. Working alongside front and rear cameras, they evaluate light sources, optimize white balance, and compensate for flicker. For humanoid robots, this ensures **stable image processing** in environments with variable illumination—critical for accurate object recognition, gesture interpretation, and safe navigation.

Time-of-Flight (ToF) sensors provide precise distance and depth measurements, enabling robots to detect obstacles, plan collision-free paths, and interact safely with humans. These sensors incorporate advanced components such as **VCSEL emitters** for structured light projection and SPAD arrays for photon-level detection. Their ultralow-power architecture supports continuous depth sensing without compromising energy efficiency, which is vital for mobile robots operating over extended periods.

High-resolution 3D ToF cameras extend these capabilities by generating detailed depth maps for complex environment mapping, posture estimation, gesture and small objects recognition. Such features are fundamental for humanoid robots performing tasks in dynamic settings where understanding human presence and movement is key to safety and collaboration.

Beyond basic ranging, modern sensors contribute to **scene understanding** and adaptive vision. Features like touch-to-focus and dynamic focus adjustment allow robots to refine perception in real time, improving their ability to interpret complex surroundings and respond appropriately.

Key implications for humanoid robotics:

- **Reliable vision in variable lighting** for accurate recognition and navigation
- **Precise spatial awareness** for safe locomotion and obstacle avoidance
- **Human posture and gesture detection** for natural interaction
- **Energy-efficient depth sensing** for extended operational autonomy
- **Precise inspection and measurements**

Key benefits of ToF		Key benefits of CMOS image sensors			Key benefits of ALS		
From sensing to 3D depth with high resolution in a compact all-in-one module		Bring computer vision with tiny high resolution, high sensitivity, low power image sensors			Improve robot vision with accurate Lux and CCT and flicker removal		
Single-point AF assist Touch-to-focus	User interaction & safety	Capture images to record videos	recognize features	Inspect & measure parts	Measure light & color information	adapt display seetings	remove flicker effects

3D DEPTH AND dToF MEASUREMENT AND ENVIRONMENTAL MAPPING

ST provides a portfolio of **direct Time-of-Flight (dToF)** and **3D depth sensing** solutions designed for high-precision depth measurement and imaging in robotics and automation.

dToF technology calculates the time a light pulse takes to travel to an object and return, enabling accurate ranging for tasks such as **navigation, obstacle avoidance**, and **environment mapping** in humanoid and industrial robots.

Complementing this, ST's 3D depth sensing products capture detailed three-dimensional representations of objects and surroundings. These capabilities support **object detection, gesture recognition**, and **scene understanding**, which are critical for **human-robot interaction** and autonomous decision-making in dynamic environments.

By combining advanced optical components with efficient processing architectures, these solutions deliver reliable performance for robotics applications where precision, speed, and adaptability are essential.

Part number	General description	Operating range distance (m) max	FOV (°) (diagonal)	Supply voltage (VDD) (V) min	Supply voltage (VDD) (V) max	Zones	Grade	Ultralow power
VL53L9CX*	3D dToF all-in-one LiDAR module with on-chip processing for Mass Market	9	HxV 55°x42°	2.8	4.8	2.3 K	Industrial	Yes
VD55H1	Low power, low noise 3D iToF 0.5 Mpix sensor die	5	65	1.1	5	-	Industrial	-

Note: * Available Q1'26

dToF module

Part number	General description	Operating range distance (m) max	FOV (°) (diagonal)	Supply voltage (VDD) (V) min	Supply voltage (VDD) (V) max	Zones	Grade	Ultralow power
VL53L0X	Time-of-Flight (ToF) ranging sensor	2	25	2.6	3.5	1	Industrial	No
VL53L1CB	Time-of-Flight (ToF) long-distance ranging sensor with advanced multizone and multiobject detection	8	27	2.6	3.5	2x2		Yes
VL53L1CX	Time-of-Flight (ToF) ranging sensor based on ST's FlightSense technology	4	27	2.6	3.5	1		Yes
VL53L3CX	Time-of-Flight (ToF) ranging sensor with multi target detection	5	25	2.6	3.5	1		Yes
VL53L5CX	Time-of-Flight (ToF) 8x8 multizone ranging sensor with wide field of view	4	65	1.8	3.3	8x8		No
VL53L7CH	Artificial intelligence enabler, Time-of-Flight (ToF) 8x8 multizone sensor with 90 degrees FoV	3.5	90	1.8	3.3	8x8		Yes
VL53L7CX	Time-of-Flight (ToF) 8x8 multizone ranging sensor with 90 degrees FoV	3.5	90	1.8	3.3	8x8		No
VL53L8CH	Artificial intelligence enabler, high performance 8x8 multizone Time-of-Flight (ToF) sensor	4	65	1.8	3.3	8x8		No
VL53L8CX	Low-power high-performance 8x8 multizone Time-of-Flight sensor (ToF)	4	65	1.8	3.3	8x8		No

2D IMAGING SENSORS

ST offers a range of **2D CMOS Image sensors** designed for high-resolution imaging and efficient integration into advanced systems. These cameras provide precise image capture and analysis, supporting applications such as **computer vision, robot vision, industrial automation**, and **autonomous navigation**. They feature advanced processing capabilities and compatibility with ST's microcontrollers and processors, ensuring seamless integration into complex architectures.

With an emphasis on **performance, reliability**, and **energy efficiency**, these cameras enable accurate visual perception in environments where precision and speed are critical. Support for multiple communication interfaces ensures flexibility across diverse robotic and automation platforms.

Part number	Resolution/array size	Chroma	Shutter	Pixel size (µm)	Optical format	Output format	Frame rate operation (Fps)
VB1943	5.08 MP	RGB-IR, package	Global and rolling	2.25	1/2.5"	MIPI CSI-2	100 fps (full resolution)
VB5943	5.08 MP	Monochrome,package	Global and rolling	2.25	1/2.5"	MIPI CSI-2	100 fps (full resolution)
VD16GZ	1.53 MP	RGB-IR	Global	2.61	1/4''	MIPI CSI-2	88 fps (full resolution)
VD1943	5.08 MP	RGB-IR, die	Global and rolling	2.25	1/2.5"	MIPI CSI-2	100 fps (full resolution)
VD55G1	0.56 MP	Monochrome	Global	2.61	1/9''	MIPI CSI-2, I3C	194 fps (full resolution)
VD56G3	1.53 MP	Monochrome	Global	2.61	1/4''	MIPI CSI-2	88 fps (full resolution)
VD5943	5.08 MP	Monochrome, die	Global and rolling	2.25	1/2.5"	MIPI CSI-2	100 fps (full resolution)
VD66GY	1.53 MP	RGB	Global	2.61	1/4''	MIPI CSI-2	88 fps (full resolution)

MICROCONTROLLER FOR AI PROCESSING

STMicroelectronics offers a dedicated **STM32N6** microcontroller family that integrates a neural network processor for advanced on device AI. Based on an **Arm® Cortex® M55** core running up to **800 MHz** with Helium (M Profile Vector Extension) for DSP acceleration, the device targets edge workloads that combine signal pre/post processing and inference on a single MCU.

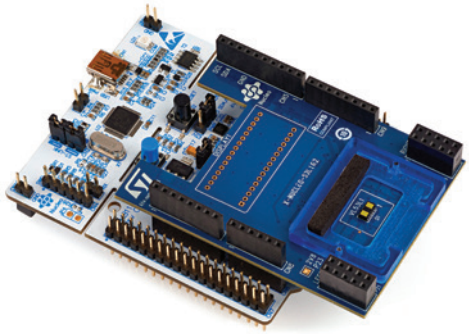
The STM32N6 embeds the in house **ST Neural ART accelerator**—an NPU clocked up to **1 GHz** delivering **up to 600 GOPS**—to execute real time neural network inference for computer vision and audio pipelines while keeping power consumption suitable for embedded systems. The platform couples the NPU with a large **4.2 MB contiguous SRAM**, a camera pipeline (parallel and MIPI CSI 2) with an image signal processor, and hardware multimedia blocks (e.g., H.264 encoder, JPEG), enabling end to end acquisition → processing → inference on the device without a host processor.

For robotics use cases, this architecture supports tasks such as object detection, pose/gesture estimation, and scene understanding at the edge, leveraging the camera interfaces and on chip acceleration to meet real time constraints typical of navigation and human robot interaction.

Part number	Package	Core	Operating frequency (MHz)	FPU	Co-Processor type	RAM size (kB)	Graphic accelerator	Cryptography	Security functions	Ethernet	Supply voltage (V) min	Supply voltage (V) max	NPU AI/NN hardware accelerator	Video HW accelerator
STM32N657A0	VFBGA 169 6x6x1.0 P 0.4 mm	Arm Cortex-M55	800	Double-precision FPU, Half-precision FPU, Single-precision FPU	Neural-ART	4200	Chrom-ART, JPEG Codec, NeoChrom GPU	AES, ECDSA, HMAC, OTF ENC/DEC, PKA, S-AES, S-ECC, S-RSA, SHA-1, SHA-2, TRNG	Abnormal Situation Handling, Application Lifecycle, Audit/Log, Crypto Engine, Identification/ Authentication/ Attestation, Isolation TrustZone, Secure Boot, Secure Install/ Update	1Gbps (IEEE 1588)	1.71	3.6	600 GOPS	H.264 encode, ISP
STM32N657B0	VFBGA 198 10x10x1 P 0.65 mm								Abnormal Situation Handling, Application Lifecycle, Audit/Log, Crypto Engine, Identification/ Authentication/ Attestation, Isolation TrustZone, Secure Boot					
STM32N657I0	VFBGA 178 12x12x1 P 0.8 mm													
STM32N657L0	VFBGA 223 10x10x1 P 0.5 mm													
STM32N657X0	VFBGA 264 14x14x1 P 0.8 mm													

TURNKEY SOLUTIONS

P-NUCLEO-53L1A2

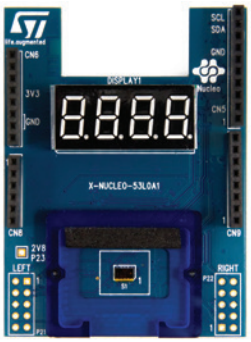


VL53L1 Nucleo Pack.

X-NUCLEO-53L1A2

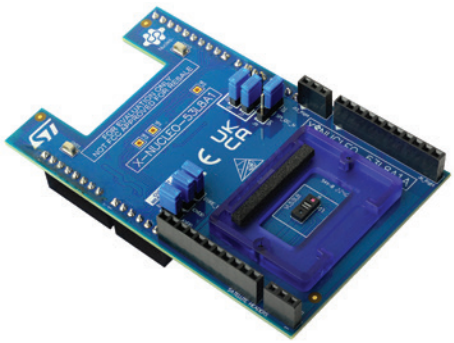
VL53L1 Nucleo expansion board.

X-NUCLEO-53L0A1



Ranging sensor expansion board based on VL53L0X for STM32 Nucleo.

X-NUCLEO-53L8A1



The X-NUCLEO-53L8A1 is an expansion board for any STM32 Nucleo board equipped with the Arduino R3 connectors. It that allows you to learn, evaluate, and develop applications based on the VL53L8 series Time-of-Flight sensors.

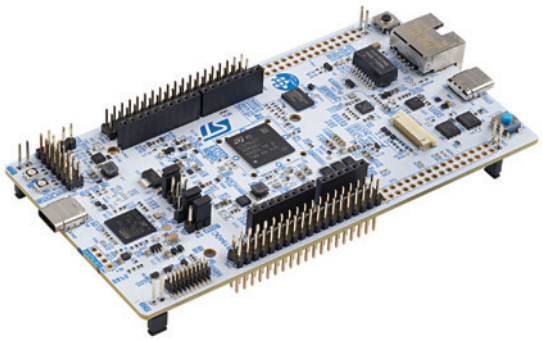
STEVAL-56G3MAI

VD56G3 S-Board MIPI CSI-2 kit for integrating VD56G3 image sensor on MPU and MCU boards.

STEVAL-66GYMAI

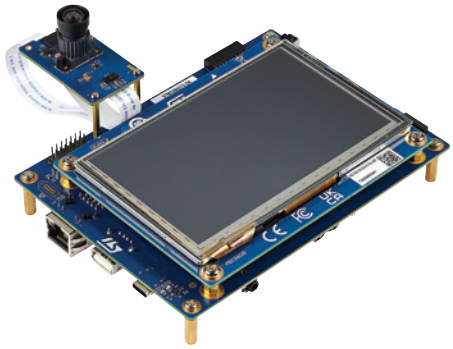
MIPI CSI-2 kit for integrating VD66GY image sensor on MPU and MCU boards.

NUCLEO-N657X0-Q



STM32 Nucleo-144, including STM32 comprehensive free software libraries and examples.

STM32N6570-DK



The STM32N6570-DK Discovery kit includes a full range of hardware features that help the user evaluate many peripherals, such as USB Type-C®, Octo SPI flash memory and Hexadeca SPI, Ethernet, camera module, LCD, audio codec, digital microphones, and others.

Backbone Components

SECURE ELEMENT TO SECURE ROBOT HEAD UNITS AND ENSURE AUTHENTICITY OF SUB-COMPONENTS

Robotics offer great versatility, addressing a wide variety of needs, with many robot solutions for services in industrial, medical or consumer applications. Robots are rarely fully autonomous and are connected to a remote service operated from the Cloud. Whatever the vertical, robots are therefore often part of an upper global system which is exposed to the same security threats, such as ID cloning, data manipulation, privacy breaches, and malware injections.

Robots are also an ecosystem on their own, built with smart components that are connected to one another. The consistency of the robot's behavior relies on the trustworthiness of its sub-components. Therefore, these sub-components and their exchanges must be protected in the same way against security threats that are ID cloning, data manipulation, privacy breaches, and malware injections.

STSAFE secure elements provide a hardware root of trust that protects head units, smart sub components, and consumables.

STSAFE-A secure elements for robot head unit and smart components

STSAFE-A is a product family of secure elements, providing authentication and secure data management services to end-devices, such as a robot or a sub smart-component.

In robotic systems, this means:

- **Strong authentication:** thanks to personalized certificates enabling strong authentication, only authorized equipment or sub-components are allowed to enter the system
- **Data integrity and confidentiality:**
  - Preventing data exchange from being manipulated with data signature
  - Preventing privacy breach in data flow with TLS establishment
- **Platform integrity:** ensure the equipment platform integrity by verifying the signature of the application before execution or update

The STSAFE-A is a companion chip to the connected device's main processor, via simple I²C interface. Based on a CC EAL5+-certified platform, the STSAFE-A secure elements are pre-provisioned with keys and certificates that are loaded at ST secure manufacturing sites.

Product name	Product features	Interface	Certification	Package options	Operating temperature range	NVM storage
STSAFE-A120	• Authentication with personalized X 509 certificates • Secure connection (TLS) • Symmetric encryption and decryption • Secure data storage and counters • Signature verification • Remote cloud authentication • Amazon AWS JIT and Microsoft Azure DPS device enrollment	I²C	CC EAL5+ HW	SO8N 4x5 mm DFN8 2x3 mm	From -40 °C to +105 °C	16 Kbytes

STSAFE-L secure elements for robot sub-components, consumables and batteries

Many robots rely on interchangeable consumables and passive sub components such as batteries, medical consumables, or accessories. These items are prone to cloning, unauthorized reuse, or uncontrolled life extension, which can degrade system performance, violate safety limits, or erode business models.

STSAFE L is optimized for this scenario, providing:

- **Anti cloning** through authentication with personalized certificates, ensuring only genuine sub-components, consumables and batteries are accepted by the robot
- **Usage monitoring** thanks to secure counters and secure data storage, it allows to limit the number of usage of a consumable to avoid overuse

Like STSAFE A, STSAFE L devices are pre personalized at ST secure manufacturing sites with unique IDs, certificates, and keys. The STSAFE-L is directly mounted on the sub-components or consumables and connected to the host device MCU via I²C or ST1Wire.

Product name	Product features	Interface	Package options	Operating temperature range	NVM storage
STSAFE-L010	• Authentication with generic or personalized certificates • Asymmetric Edwards curves • Secure data storage and secure counters	I²C ST1Wire	DFN8 2x3 mm DFN6 1.4x1.6 mm Contact DFN3 4x3.2 mm	From -25 °C to +85 °C	32 kbytes EEPROM

ST4SIM eSIM

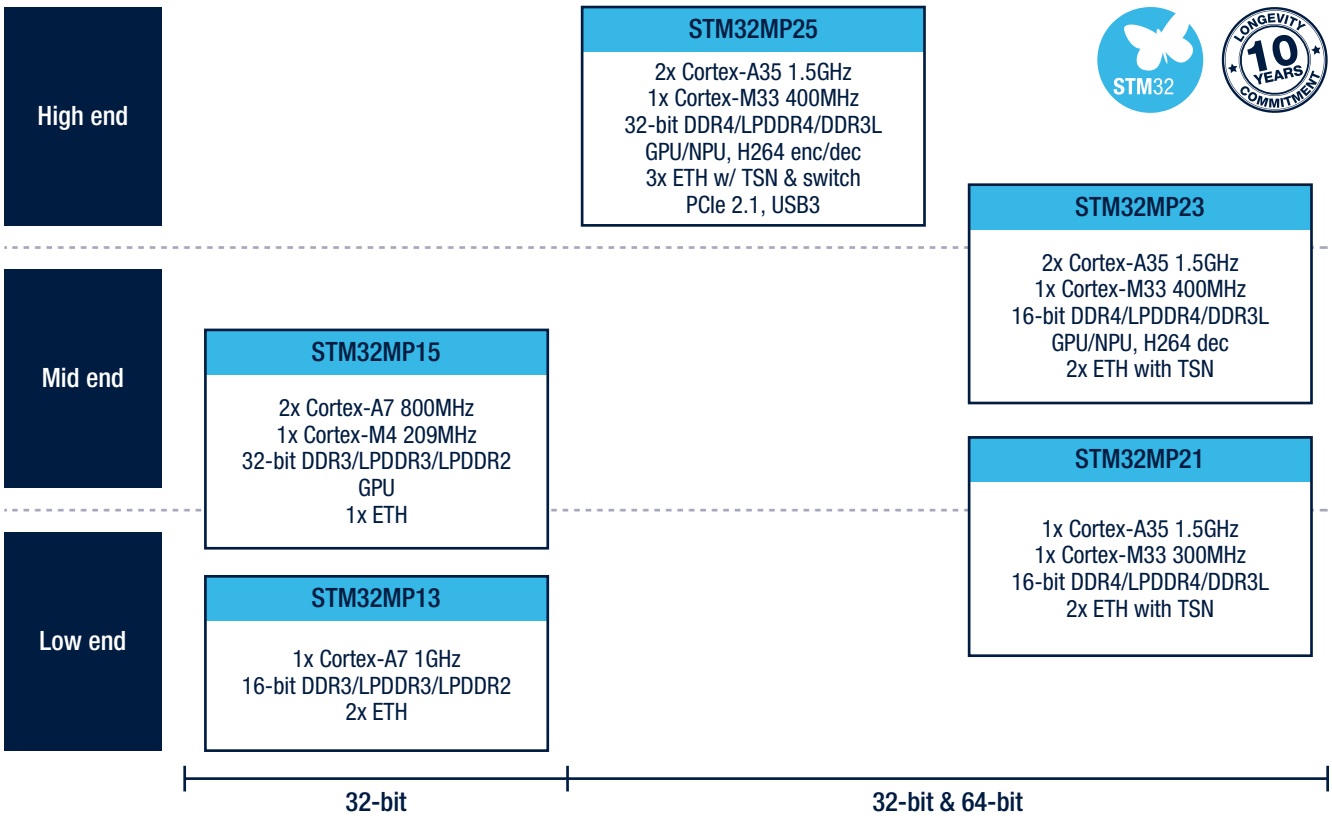
Securely identifies and authenticates the Humanoid on a mobile network, allowing the operator to provide data connectivity services used for robot fleet management, telemetry, tracking, and remote diagnostics. The ST4SIM complies with the latest GSMA specifications for Remote SIM Provisioning (RSP) and is fully compatible with NB-IoT networks. Thanks to RSP protocols and the availability of bootstrap connectivity, the ST4SIM can localize the connectivity provider based on the country where the Humanoid is located. Optionally, the ST4SIM can be configured to guarantee continuous connectivity by detecting a loss of connection with a given enabled network operator and automatically switching to another pre-loaded operator with data coverage.

Part number	General Description	Features set	Product Function	Communication interfaces	Certification
ST4SIM-300M	GSMA eSIM for IoT system-on-chip solution for IoT environment	M2M	eSIM	Contact ISO7816, I2C, SPI	CC EAL6+, GSMA

ZONAL PROCESSOR

In a humanoid robot with a zonal electronics architecture, each microprocessor (MPU) serves as an intelligent hub managing sensing, actuation, and communication within its physical zone (head, torso, arms, legs). It locally fuses data from cameras, LiDAR, IMUs, and tactile sensors, executes real-time control loops for motion and safety, and forwards only relevant, pre-processed information to the central computer.

The STM32 family of general-purpose microprocessors is well suited for this role, combining high-performance application cores for Linux and AI workloads with real-time microcontroller cores for deterministic control. Its rich connectivity supports Ethernet switch with TSN, industrial fieldbuses, and high-speed sensor interfaces. This heterogeneous design enables each zone to offload perception, control, and safety tasks from the main brain, minimizing wiring complexity and supporting modular, scalable, and power-efficient robot architectures. With integrated GPU and NPU for edge AI inference and built-in secure communication, the MPU transforms each zone into a smart, autonomous node ready for advanced locomotion, manipulation, and human–robot interaction.



MEMORIES

Serial EEPROM for storage, calibration, datalogging, and counters

Serial EEPROMs provide long-term data retention and high cycling endurance, making them ideal for reliable, low-power storage in a small form factor. They are commonly used for baseline settings, decision thresholds, or event logging associated with processors, cameras, sensors, actuators, or communication nodes. Performance is preserved across power cycles, mechanical servicing, or sensor replacement. Byte-level flexibility allows firmware to update individual parameters without block-erase constraints, minimizing write overhead on microcontrollers. Low voltage and low power consumption reduces energy use and heat dissipation ideal for sensitive analog front-ends, exposed surfaces, and battery-powered subsystems.

Part number	General description	(Other key attributes)
M24512E-F	512 Kbit Serial I2C bus EEPROM 2-Mbit SPI bus EEPROM with high-speed clock	Configurable device address register Software write protection register Additional 128-byte or 256-byte identification page
M95M02E-F		

Serial Page EEPROM for real-time, high-volume datalogging

Serial Page EEPROM is the ideal memory solution to complement STM32 MCUs with ultra-low-power consumption, firmware storage, and FOTA updates. It combines very short wake up times, operation status flags, fast erase, program and long-term data retention with embedded ECC for safe and performant firmware management. Short page-program and write with byte flexibility enable real-time or random configuration updates efficient event logging with fewer cycles. Serial Page EEPROM delivers reliable performance for high-volume datalogging with up to 500k write cycles with 100 years data retention at 55 °C.

Part number	General description	(Other key attributes)
M95P08-I	Ultra low-power 8 Mbit Serial SPI Page EEPROM	High write/erase performance ECC for high memory reliability (DEC, TED) Operating status flags for ISO26262
M95P16-I	Ultra low-power 16 Mbit Serial SPI Page EEPROM	
M95P32-I	Ultra low-power 32 Mbit Serial SPI Page EEPROM	

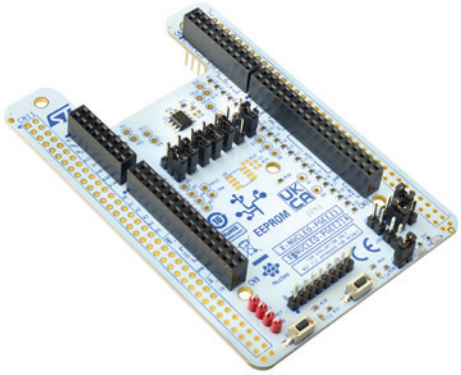
UID EEPROM for identification and traceability

UID EEPROM combines the robustness of serial EEPROM with a factory programmed unique identifier, offering a simple way to identify every humanoid robot unit, subsystem, or modular component and detect duplicates. With **4 million write cycles endurance and 200 years of data retention**, UID EEPROM simplifies inventory management and maintenance programs for modular components like batteries, tool modules, or accessories. The UID can be associated with a digital twin or with manufacturing data, service dates, and other useful information for traceability and maintenance. Industry-standard I²C interfaces and drop-in compatibility with serial EEPROM footprints make it easy to integrate UID EEPROM to deploy ready-to-use traceability for robot units and components.

Part number	General description	(Other key attributes)
M24256E-U	256-Kbit serial I2C bus EEPROM with unique identifier	Configurable device address register

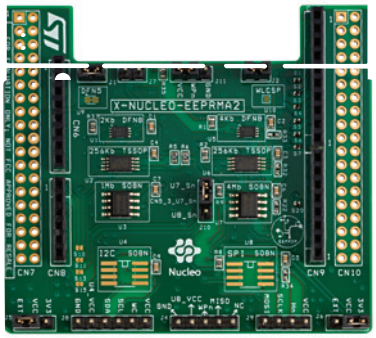
TURNKEY SOLUTIONS

X-NUCLEO-PGEEZ1



Standard SPI page EEPROM memory expansion board based on M95P32 series for STM32 Nucleo.

X-NUCLEO-EEPRMA2



Standard I²C and SPI EEPROM memory expansion board based on M24xx and M95xx series for STM32 Nucleo.

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