Technical White Paper
mmWave Radar for Robotics

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ABSTRACT

Robots operating alongside humans in structured environments, such as factory floors, fulfillment centers, and hospitals, as well as unstructured environments like outdoor delivery, face sensing challenges that cameras, LiDAR, and Time-of-Flight (ToF) sensors alone cannot solve. mmWave radar provides a complementary, lighting-independent detection layer with native velocity measurement, transparent-surface detection, and functional safety certification options that no other modality offers.

Every active sensor measures the world by emitting energy and timing the return. What differentiates sensor modalities is which physical property of that return that each type measures and how that property behaves across real operating conditions. Radar transmits radio-frequency energy, which reflects from surfaces regardless of ambient lighting and penetrates dust, steam, and airborne particulates that scatter or block optical wavelengths. Unlike cameras and LiDAR, radar reflects strongly from human tissue through clothing and detects glass and specular surfaces that are transparent or ambiguous to optical sensors. These properties are not edge-case advantages; in industrial, fulfillment, and healthcare environments, these properties are baseline requirements.

Table of Contents

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1 Why Radar in Robotics

Cameras are the default perception modality in robotics, but cameras degrade predictably in the scenarios that matter most for safe deployment. Radar is a complementary modality that addresses gaps cameras cannot reliably fill.

Scenario	Expected Response	
	Camera Alone	**Camera and mmWave Radar**
Low-light or no-light environment	Degraded or failed detection	Radar performance is lighting-independent, detection maintained where camera degrades
Fog, dust, condensate, smoke	Occlusion and missed detections	Radar is significantly more robust to particulates, detection maintained in conditions that challenge camera
Glass walls, clear packaging, mirrors	Invisible or misclassified	Glass transmits light rather than reflecting light; polished surfaces deflect light away from the lens. Radar returns from any solid surface regardless of optical transparency
Human versus robot versus object classification	Effective in well-lit conditions; degrades at range or under lighting variation	Radar micro-doppler signatures provide an additional classification signal independent of lighting and visual appearance
Object velocity measurement	Requires frame differencing, latency and noise increase at low frame rates	Native per-point doppler velocity measurement, no frame differencing required
Safety bubble zone enforcement	Limited native velocity data at zone boundary; potential FOV gaps	Range and velocity together support dynamic zone definition and enforcement
Factory and warehouse safety	Camera-based systems can degrade under industrial lighting variation, dust, and steam.	Adding a radar layer provides a lighting- and environment-independent detection input with IEC 61508 safety integrity level (SIL) 2 certified hardware integrity

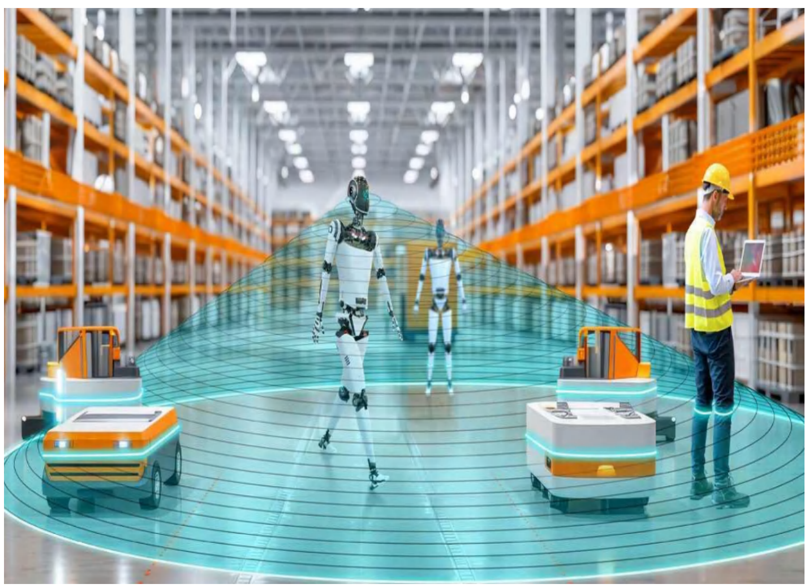

Figure 1-1. Humanoid Robot Interacting With Physical Environment

2 Why TI mmWave FMCW Radar for Robotics?

TI mmWave FMCW radar transmits a sequence of frequency-modulated pulses (chirps) and processes the reflected returns to extract three independent measurement dimensions from every detected surface:

- **Range** — Refers to the round-trip time delay of each chirp return, resolved to centimeter-level accuracy using FMCW processing
- **Radial velocity** — Refers to the Doppler phase shift between successive chirps; velocity is measured directly, not estimated from a tracking filter
- **Angle (azimuth or elevation)** — Refers to the phase difference across the receive antenna array; multiple Rx elements resolve 2D angular position to produce a 3D point cloud

The short wavelength enables compact antenna arrays with meaningful angular resolution in a form factor compatible with robot body dimensions. Radial velocity is available per-point on every frame, no multi-frame tracking required, making millimeter-wave radar the only modality that provides instantaneous velocity-tagged 3D point clouds across all operating conditions. In a multi-modal sensor stack, radar is a natural complement to cameras and LiDAR. Radar contributes information that these other modalities cannot independently provide.

3 Radar Products for any Robotics Application

TI's radar portfolio spans the full performance range needed across robotics market segments: high-performance front-end transceivers deliver the range, resolution, and processing power needed for humanoid and mobile robots to sense and map the surroundings, while compact, integrated system-on-chip (SoC) devices provide low-power, short-range sensing for tasks like detecting nearby objects or guiding a robotic arm. The right device depends on range, resolution, processing architecture, power budget, and regulatory environment.

Two Portfolio Tiers: TI's robotics radar portfolio consists of High-Performance Radar and Low-Power Radar product families. Both portfolios include devices operating in the 60GHz band (57–64GHz) and the 77GHz band (76–81GHz), allowing customers to select the appropriate design based on application requirements and regional regulatory compliance.

High-Performance Radar devices are designed for applications requiring longer detection ranges, high angular resolution, and advanced signal processing, supporting sensing distances from a few centimeters to several hundred meters. This portfolio includes cascadable front-end transceivers, and single-chip SoC (System on Chip) radar sensors. Cascadable devices can be combined to achieve very high virtual antenna counts and exceptional angular resolution, making these devices an excellent choice for imaging radar and LiDAR replacement applications. Single-chip SoCs integrate the RF front end, DSP, hardware accelerators, and processing into a complete radar design, with configurations up to 4 transmit and 4 receive channels, while cascaded systems can scale from 8T8R to 32T32R and beyond. High-performance devices also use launch-on-package (LoP) technology to maximize RF performance.

Low-Power Radar devices are designed for battery-powered and power-constrained systems where energy efficiency is critical. These products are appropriate for short-range sensing applications such as range finding, presence detection, occupancy sensing, and PIR replacement. Low-power devices also feature antenna-on-package (AoP) technology, enabling highly compact system designs while maintaining robust sensing performance.

4 TI mmWave Radar Portfolio for Robotics

TI's portfolio offers several products, and the choice is driven by range, resolution, processing architecture, and power constraints applicable to each end equipment in the robotics market.

Devices	Frequency Band	Cascadable	Architecture	Package	Recommended Ranges	Range Resolution	Achievable Angular Resolution	AI Capability	Safety	Interface
IWR6243	57–64GHz	YES	Front end only	Standard	0.1–500+ m	2.14cm	<1° (cascaded 12Tx × 16Rx)	NO	IEC 61508 up to SIL 2	CSI-2 (MIPI), SPI, I^{2}C, UART
IWR2188	76–81GHz	YES	Front end only	LOP	0.1–700+ m	3.75cm to 15cm	<0.5° (cascaded 16Tx × 16Rx, 24Tx × 24Rx, 32Tx × 32Rx)	NO	IEC 61508 up to SIL 2	CSI-2 (MIPI), SPI, I^{2}C, UART
AWR2944P	76–81GHz	NO	Front end, HWA2.1 400MHz, DSP C66x, MCU, HSM	Standard	0.1–300+ m	3.75cm to 15cm	approximately from 4 to 6°	YES	ISO26262 up to ASIL B	SPI, CAN-FD, UART, I^{2}C, Ethernet 1Gbps
AWR2E44P				LOP						
IWR6843	60–64GHz	NO	Front end, HWA1.0 200MHz, DSP C67x, MCU	Standard	0.1–100+ m	3.75cm	approximately 15° az or approximately 15° el	YES	IEC 61508 up to SIL 2	CAN-FD, SPI, I^{2}C, UART
IWR6843AOP				AOP	0.1–50 + m					
IWRL6844	57–64GHz	NO	Front end, HWA1.2 200MHz, DSP C66x, MCU	Standard	0.1–100+ m	2.14cm	approximately from 4 to 6°	YES	IEC 61508 up to SIL 2	CAN-FD, SPI, I^{2}C, UART
IWRL6432	57–64GHz	NO	Front end, HWA1.2 200MHz, MCU	Standard	0.1–30 + m	2.31cm	approximately 26° az or approximately 42° el	YES	IEC 61508 up to SIL 2	CAN-FD, SPI, I^{2}C, UART
IWRL6432AOP				AOP	0.1–20m					

5 Robotics Market Requirements – What Radar Solves

TI's radar portfolio addresses distinct technical requirements across four robotics market segments. Each segment has different range requirements, safety constraints, and deployment environments; the recommended device tier follows from these constraints.

5.1 Humanoid and Bipedal Robots

Key applications: Human-robot coexistence, safety bubble enforcement, full-body scene awareness

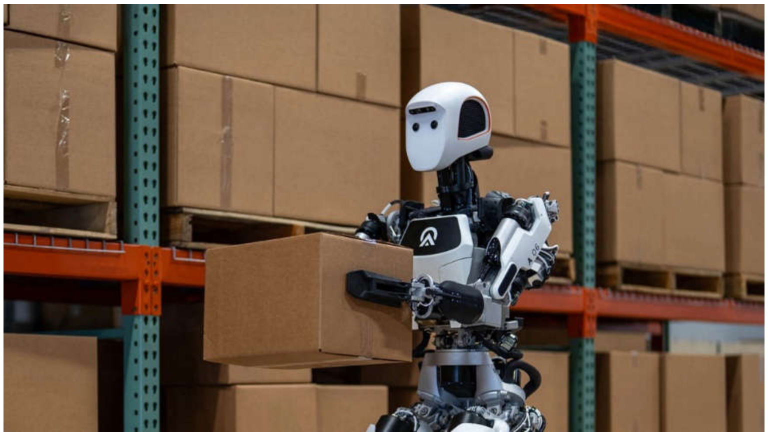

Figure 5-1. Humanoid Robot in Warehouse

- **Human-Robot Safety Bubble:** Tiered proximity zones (4 levels: stop, slow, caution, nominal) around the full robot torso. Radar provides range and velocity at each zone boundary; camera alone cannot disambiguate velocity at zone edges. IEC 61508 SIL 2 certification supports the functional safety argument required for unguarded human coexistence.
- **Human Detection and Classification:** In this application, Distinguishing human workers from other robots and static infrastructure in dense factory environments. Requires high angular resolution and per-point Doppler velocity; the output of a cascaded IWR6243 fed directly to an AI inference pipeline on NVIDIA® Jetson Thor or equivalent compute.

5.2 Autonomous Mobile Robots (AMR)

Key applications: Navigation safety, obstacle avoidance, warehouse and fulfillment sensing

Figure 5-2. Autonomous Mobile Robot Navigating Factory Floor

- **Navigation safety and obstacle avoidance:** Mobile platforms navigating shared spaces need reliable detection of humans and dynamic obstacles under all lighting conditions. Radar provides a perception layer that remains stable when camera-based systems degrade in dust, glare, or low-light warehouse environments.
- **Transparent and specular obstacle detection:** Glass walls, reflective floors, and clear packaging are invisible to cameras: glass transmits rather than reflecting light, and polished or mirrored surfaces deflect light

away from the lens. Radar returns from the surface of any solid material regardless of optical transparency. These functions are critical for AMRs navigating retail, warehouse, and fulfillment environments where these surfaces are common.
- **3D scene mapping / slam assist:** Radar augments lidar and stereo camera SLAM systems with velocity-annotated point clouds. Enables detection of moving obstacles that cameras and lidar miss and provides a cross-modal consistency check that improves localization robustness in dynamic scenes.
- **Sensor fusion depth layer:** Radar provides the velocity and range dimension that cameras lack. Combined with RGB or thermal imaging using an AI fusion pipeline, TI radar closes the modality gap for environments where any single sensor is insufficient. For an example using the IWR6243 mmWave radar sensor and a camera and deployed on NVIDIA's Holoscan platform, see Real-Time AI Raw Sensor Fusion with IWR6243 mmWave Radar and Camera on NVIDIA’s Holoscan Platform.

5.3 Industrial Fixed-Mount Radar

Key applications: Asset monitoring, crane positioning, factory floor traffic management

Figure 5-3. Industrial Fixed Robotic Arm

- **Industrial Asset and Crane Monitoring:** Stationary high-resolution radar at container terminals or industrial bays detecting large metal assets, crane position, and intrusion zones. Cascaded IWR6243 provides the angular resolution needed at 10–30m range for bulk goods detection and high-resolution container terminal mapping.

5.4 Medical and Surgical Robotics

Key applications: OR staff proximity detection, surgical arm spatial awareness

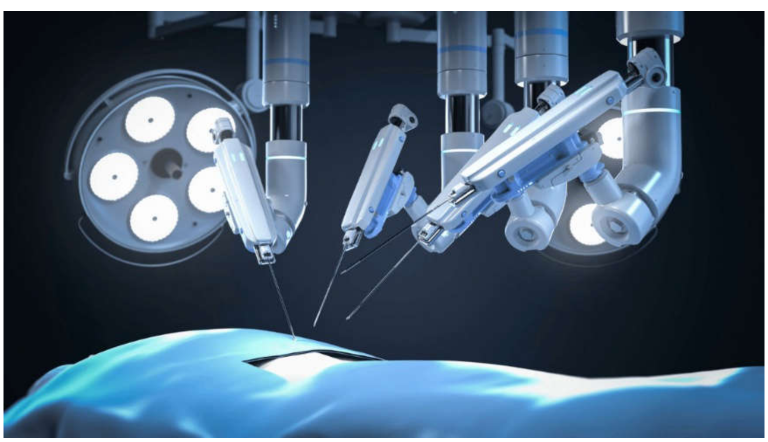

Figure 5-4. Surgical Robot Operating on Sample Surface

- **OR Staff Safety and Proximity Detection:** Surgical robotic systems operate in close proximity to patients and clinical staff in controlled environments with readily available high-performance compute. Surgical robots must stop or pause when a surgeon or scrub tech enters the arm's operating envelope.
- **Surgical Arm Spatial Awareness:** Robotic arms operating over a patient require real-time awareness of the surrounding volume to prevent unintended contact. Radar provides this spatial map independent of OR lighting conditions; overhead surgical lights, shadows, and reflective draping that challenge cameras do not affect mmWave performance.

6 Recommended Products

6.1 High Resolution IWR6243 Cascade Radar

The IWR6243 is TI's 57–64GHz FMCW radar transceiver frontend built for high-performance robotics applications, differentiated by three architectural decisions:

- **Frontend-only output using CSI-2** — raw ADC samples are streamed over a 4-lane MIPI D-PHY interface to the host compute platform, preserving full signal fidelity for host-side processing pipelines
- **Cascade architecture** — multiple transceivers are phase-synchronized using a 20GHz reference to form one large virtual aperture, directly scaling angular resolution without increasing per-chip area; cascaded systems can scale from 6Tx×8Rx to 12Tx×16Rx and beyond
- **IEC 61508 SIL 2 certification by TÜV SÜD** — satisfying the functional safety requirement common to industrial and collaborative robotics deployments

6.1.1 Reference Design

Many robotics perception applications require a known-good foundation for a design. The example explain in *Real-Time AI Raw Sensor Fusion with IWR6243 mmWave Radar and Camera on NVIDIA’s Holoscan Platform* includes a validated integration path for connecting the IWR6243 cascade EVM to NVIDIA's Holoscan platform for radar-vision sensor fusion. This design explains the validated hardware and software integration path for streaming IWR6243 raw radar data into an NVIDIA Holoscan AI pipeline alongside camera input. This example establishes the data path, software stack, and ecosystem partnerships (D3 Embedded) needed to build robotics perception applications on this platform. Performance validation for specific robotics use cases is not included.

6.1.2 Hardware Stack

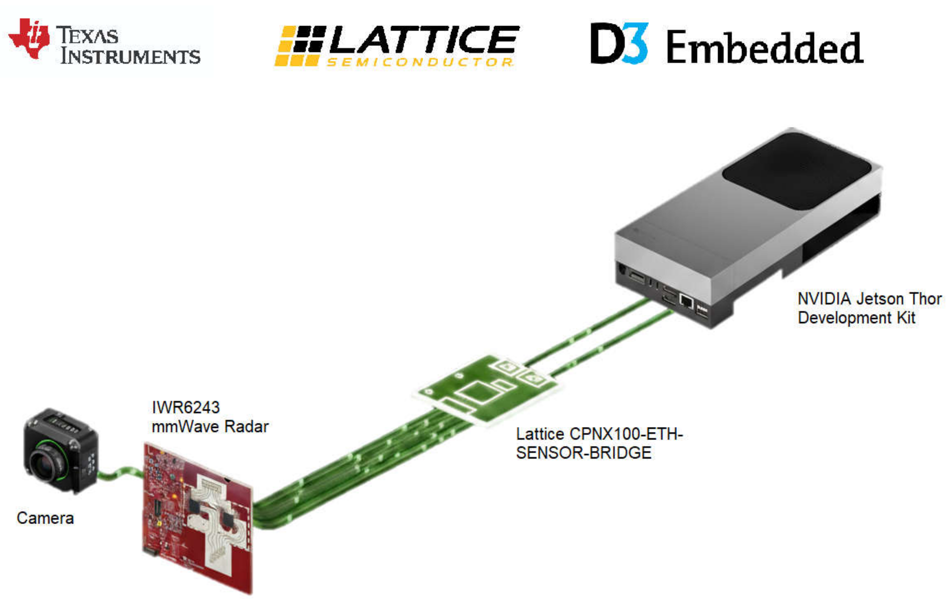

Figure 6-1. IWR6243 and Nvidia Holoscan Integration for Robotics Perception Applications

6.1.3 Software Stack

- **NVIDIA Holoscan SDK:** Graph-based execution runtime for radar signal processing, camera inference, and multimodal fusion

- **NVIDIA Holoscan Sensor Bridge SW:** Deterministic data movement from sensors into GPU memory
- **D3 Embedded application SW:** IWR6243 radar configuration, point cloud generation, camera alignment, and AI fusion logic
- **mmWaveLink SDK:** IWR6243 chirp configuration and register access

6.2 Form Factor Optimized IWR6843 AOP Radar

The IWR6843 AOP is TI's 57–64GHz FMCW single-chip radar sensor built for applications where size, power, and integration depth matter more than maximum angular resolution. Three architectural decisions differentiate this device:

- **Antenna-on-Package (AoP)** — transmit and receive antennas are integrated directly into the package, eliminating PCB antenna routing, matching networks, and RF board characterization. The result is a compact, layout-friendly module that can be placed in mechanically constrained locations: joint housing, end effectors, robot perimeters, and tight enclosures where a discrete antenna PCB does not fit
- **Full onboard signal processing** — the integrated HWA1.0 hardware accelerator, C67x DSP, and Arm® Cortex®-R4F MCU run the complete radar signal chain on-chip. Range-Doppler processing, CFAR detection, and point cloud output execute without any external host processor, reducing system component count, PCB area, and power draw compared to a front-end-only device paired with external compute
- **IEC 61508 SIL 2 certification by TÜV SÜD** — the same functional safety qualification as the IWR6243, supporting human-robot coexistence deployments where certified hardware integrity is required by the safety argument

The IWR6843 AOP targets use cases where each sensor node must be self-contained: proximity detection around robot limbs, safety bubble enforcement on collaborative arms, and short-range obstacle sensing in battery-powered AMRs where a dedicated radar host is not available or not justified.

6.2.1 Reference Design

The *mmWave radar sensing reference design for safer robot perception* reference design guide provides a validated hardware foundation for deploying the IWR6843AOP in certified robotic systems. This design is a fully assembled performance-validated board paring pairs the IWR6843AOP radar with the LP87745 safety PMIC.

This design guide explains Q&A watchdog communication between PMIC and radar, level and PWM error signal monitoring (ESM), safety diagnostics, and radar reset using the hardware-side building blocks of a SIL 2 compliant robot perception module. The example used in the TIDA-010281 design guide also shows verified test results for watchdog communication, error signal monitoring, safety diagnostics, and radar reset. These results give developers a known-good starting point for SIL 2 compliant robot perception nodes targeting AMRs, AGVs, humanoids, and collaborative robots.

Supplementary documentation, including schematics, BOM, and Gerbers, are available on the TIDA-010281 tool page.

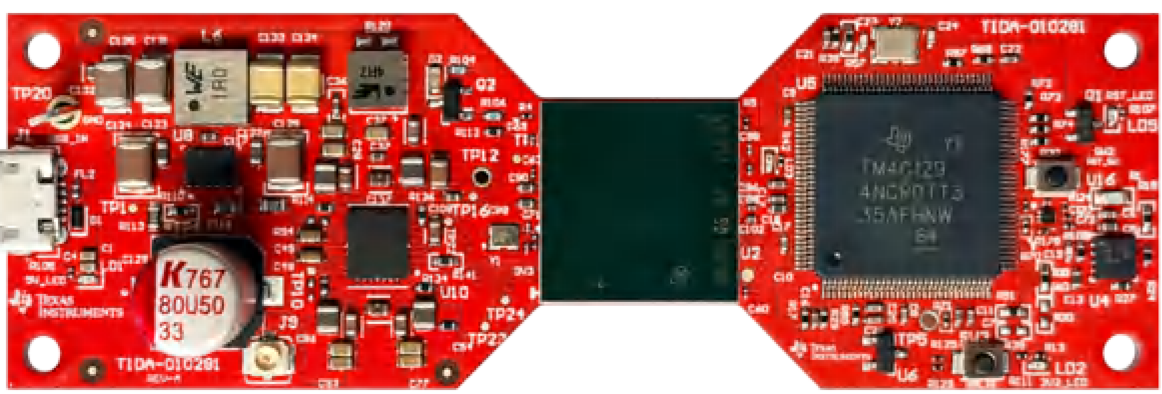

Figure 6-2. TIDA-010281 Reference Design for Safe Perception in Robotics

7 Design and Documentation Support

7.1 Tools and Software

Tools

MMWAVE-SDK mmWave software development kit (SDK) for xWR1443, xWR1642, xWR1843, xWR6443 and xWR6843

NVIDIA Holoscan SDK A multi-modal computing platform designed for real-time, scalable, and software-defined processing of streaming edge data.

Software

D3 Embedded application SW Facilitates IWR6243 radar configuration, point cloud generation, camera alignment, and AI fusion logic

NVIDIA Holoscan Sensor Bridge SW Holoscan computing platform which delivers the accelerated, full-stack infrastructure for scalable, software-defined, and real-time processing of streaming data running at the edge

7.2 Documentation Support

- Texas Instruments, *mmWave radar sensors*, webpage
- Texas Instruments, *Real-Time AI Raw Sensor Fusion with IWR6243 mmWave Radar and Camera on NVIDIA's Holoscan Platform*, application brief

7.3 Resources

IWR6243	Product Folder
IWR6843AOP	Product Folder
IWR6843	Product Folder
IWR6443	Product Folder
IWRL6432	Product Folder
IWRL6432AOP	Product Folder
AWR2188	Product Folder
AWR2944	Product Folder
AWR2944P	Product Folder
TIDA-010281	Design Folder

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