

QiSPS: Quantum Intelligence Sensor Processing System for Military Vehicle-Based Navigation, Detection, and Encryption

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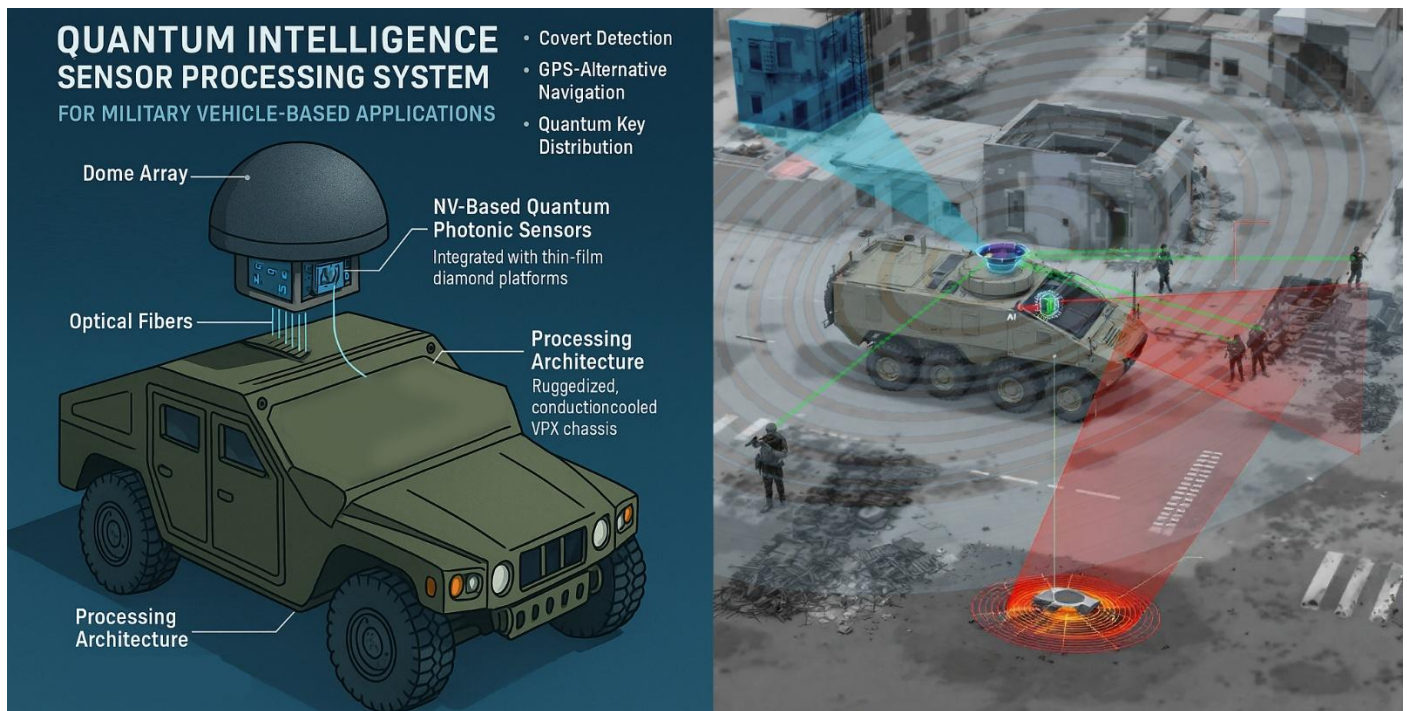


FIGURE 1 Quantum Intelligence Sensor Processing System (QiSPS) for Next-Generation Defense Platforms

ABSTRACT

This technical report details the Quantum Intelligence Sensor Processing System (QiSPS), a state-of-the-art, vehicle-mounted sensor architecture that enables covert detection, precision navigation in GPS-denied environments, and quantum-secure communications. At the heart of QiSPS lies a quantum photonic sensor array based on thin-film nitrogen-vacancy (NV) centers in diamond, integrated with silicon photonic circuits. This configuration enables the detection of weak magnetic field signatures associated with battlefield threats, including concealed firearms, explosive devices, unmanned aerial systems, and vehicles, even in environments heavily saturated with electromagnetic interference [1][2].

QiSPS operates passively and emits no detectable signals, making it inherently resilient to jamming and interception. The platform integrates artificial intelligence for real-time anomaly classification and tactical decision support, while an optical communication backbone supports quantum key distribution (QKD), enabling secure communications between vehicles and command structures. QiSPS is modular and conforms to the ½ SAVE envelope standard, allowing integration into diverse ground and naval platforms and facilitating its adoption as a mesh-networked sensor node across multi-domain operations.

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1 | INTRODUCTION

The increasing complexity of the electromagnetic battlespace has rendered many traditional sensing technologies vulnerable to spoofing, jamming, or detection. Radar, infrared, and acoustic systems, though widely deployed, are increasingly ineffective against adversaries employing advanced electronic countermeasures. In contrast, quantum-enhanced sensing technologies offer a path toward low-observable, high-fidelity threat detection and resilient navigation in denied environments. The QiSPS system responds to these emerging demands by integrating thin-film nitrogen-vacancy centers into silicon photonic platforms, enabling quantum magnetometry at room temperature with exceptional sensitivity and scalability [3]. Nitrogen-vacancy centers are point defects within the diamond lattice that consist of a substitutional nitrogen atom adjacent to a lattice vacancy. These quantum systems exhibit spin-dependent fluorescence, which can be interrogated through optically detected magnetic resonance (ODMR) techniques. When implemented in thin-film diamond layers and coupled with photonic waveguides, NV centers form the basis for compact, chip-scale quantum sensors capable of detecting femtotesla-level variations in magnetic fields [1]. These properties allow QiSPS to detect battlefield threats through their inherent magnetic signatures, even when conventional detection methods fail. Furthermore, by combining magnetic field sensing with inertial navigation subsystems and QKD communication infrastructure, QiSPS represents a unified solution for intelligence, navigation, and secure communication under a single architectural paradigm.

2 | SYSTEM ARCHITECTURE

The physical architecture of QiSPS is centered on a hemispherical dome mounted atop the host vehicle. This dome, constructed from radar-absorbent carbon fiber composite, is designed for thermal and electromagnetic stealth. Internally, the dome houses an array of thin-film NV-based sensor modules arranged in a geodesic configuration, providing 360-degree magnetic field coverage except for the vehicle's shadowed footprint. The sensors are mounted on shock-isolated platforms and shielded by mu-metal linings and Faraday cages to suppress interference from vehicle electronics. Each sensor module integrates a thin-film diamond layer—typically a few microns in thickness—embedded with ensembles of NV centers and bonded to a silicon photonic waveguide substrate. This allows for on-chip optical routing, excitation, and emission detection. These sensors exploit the Zeeman effect to detect local magnetic field variations through ODMR readout techniques, with sensitivity thresholds as low as 10-30 femtotesla per square root Hertz under ambient conditions [3][4]. The use of ensemble NV

centers enhances signal-to-noise ratio and supports wide-area sensing through large-area integration. Photonic routing is achieved through wavelength-division multiplexed (WDM) waveguides and 24-channel optical fibers terminated with MT ferrules conforming to the VITA 66.5 standard. Each optical fiber supports up to 32 multiplexed sensor channels, and the form factor of each sensor module—measuring approximately 30 mm³—allows for a high-density array arrangement within the dome. These sensors are connected to a ruggedized, conduction-cooled 3U VPX processing chassis, which adheres to MIL-STD-810G and MIL-STD-461 standards for thermal and electromagnetic performance.



FIGURE 2 Cuantico Innovation SL CU41 (1/2 ATR) and CU41S (1/2 SAVE) 100G conduction-cooled VPX ATR

The computational subsystem of QiSPS includes a heterogeneous processing stack comprising a Xilinx Ultrascale+ or Versal ACAP RF System-on-Chip (RFSoC), a GPU accelerator (such as the Jetson AGX or RTX A2000), and a single-board computer (SBC) for system orchestration. The RFSoC performs real-time demodulation, fast Fourier transforms (FFTs), and signal conditioning from the NV sensor array, while the GPU executes AI-driven threat classification models trained on magnetic signature datasets. The SBC operates a hardened Linux OS that handles sensor fusion, control logic, data logging, and tactical communication with external command networks. Additionally, the VPX chassis includes an open slot for VITA 67.3-compatible radio frequency payloads, enabling optional integration with signals intelligence (SIGINT) and electronic warfare (EW) systems.

All optical and power interfaces are routed through MIL-DTL-38999 Series III circular connectors. The optical fibers are shielded for electromagnetic compatibility and protected from electrostatic discharge. Internally, the data routing network employs secure multiplexers with radiation-hardened optical isolators, ensuring signal integrity even under directed energy attacks or transient spikes.



3 | OPERATING PRINCIPLES

QiSPS functions by detecting ambient magnetic field perturbations using the quantum mechanical spin states of NV centers. The system illuminates each NV layer with green laser light, causing the centers to fluoresce red. Variations in the external magnetic field modulate the electron spin sublevels of the NV ensemble, which in turn shifts the fluorescence intensity in a quantifiable manner. These modulations are captured through ODMR protocols and digitized by the RFSoc card for real-time processing. Machine learning algorithms classify these spectral signatures according to pre-trained templates representing various threat objects, including concealed weapons, drone rotors, armored vehicle drivetrains, and buried explosive devices. Since the QiSPS platform operates entirely in the optical and quantum domains, it emits no RF signals, rendering it effectively invisible to adversary electronic surveillance. The high-fidelity nature of the data pipeline—from NV resonance detection to real-time AI inference—enables fast, accurate threat detection with minimal false positives [4].

The QiSPS platform also supports quantum-secure communications via an integrated optical transceiver that enables quantum key distribution over short-range line-of-sight laser links. This supports secure intra-vehicle and inter-node communication in the tactical mesh, ensuring data integrity and cryptographic resilience even in compromised RF conditions [5].

4 | NV CENTERS FOR GPS-ALTERNATIVE NAVIGATION

The NV-based magnetometers in QiSPS contribute directly to inertial-magnetic navigation capabilities. By monitoring magnetic field gradients and combining these with microelectromechanical system (MEMS) accelerometers and gyroscopes inertial data, the system performs dead-reckoning localization in environments where GPS signals are degraded, jammed, or spoofed. The use of quantum magnetic signatures provides an additional spatial correlation layer that enhances positional accuracy and reduces drift over time [6]. This hybrid navigation architecture is autonomous and infrastructure-free, enabling sustained operation in subterranean, underwater, or urban environments with poor satellite visibility. QiSPS can be deployed across vehicle fleets, unmanned aerial systems, and naval assets, providing a common positioning solution across all domains. The system’s AI-enhanced path prediction engine continuously recalibrates based on sensor fusion inputs, ensuring robust navigational awareness over extended missions.

The QiSPS system’s non-GPS navigation capability may be configured as a fully independent, compact, stand-alone

micro sensing dome, housed within a ballistic-resistant polycarbonate shroud to provide impact protection and environmental durability. Due to polycarbonate’s magnetic transparency, the protective enclosure does not impair the NV sensor’s performance. This low-profile, modular sensor unit can be seamlessly integrated across a wide range of current military platforms.

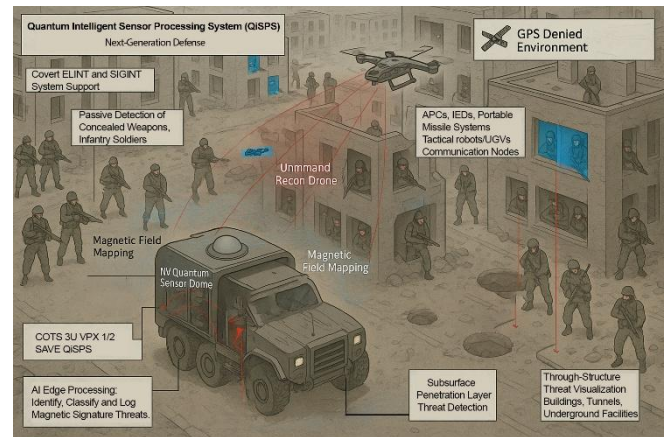


FIGURE 3 QiSPS operating in Urban Operations (UO)

5 | DEPLOYMENT AND ADAPTABILITY

QiSPS is theorized for rapid deployment across a broad spectrum of military platforms. Its physical and logical modularity ensures compatibility with tactical ground vehicles such as MRAPs and JLTVs, as well as fixed installations at forward operating bases or naval patrol vessels. The system conforms to the Standardized A-Kit / Vehicle Envelope (SAVE) envelope standard for modular payload integration, allowing for plug-and-play installation and ease of maintenance in the field. Its software-defined operating modes allow adaptation to diverse operational contexts, including open terrain, subterranean corridors, and cluttered urban battlefields. The system supports integration with third-party electronic warfare suites, drone interdiction systems, and distributed SIGINT arrays. In multi-vehicle deployments, QiSPS nodes form a mesh network that shares threat data and navigation inputs in real time, enabling coordinated maneuvering, swarm-based reconnaissance, and distributed anomaly triangulation.

6 | INVESTIGATION ROADMAP

Investigation in to future enhancements to the QiSPS platform should focus on improving sensor fidelity, reducing power consumption, and expanding operational versatility. Research into scalable quantum magnetometry is



advancing the QiSPS platform toward practical long-range detection of concealed threats, including weapons, IEDs, and drones. An advanced phased-array dome configuration is currently under investigation. This innovation will enable vector-resolved directional magnetometry using principles akin to beamforming in phased-array radar, implemented via synthetic aperture magnetometry. This configuration will allow the system to concentrate sensitivity and resolution along a specific line of interest while maintaining omnidirectional background monitoring. Central to this effort are wide-field sensors based on high-density NV center ensembles in $\sim 10\text{--}20\ \mu\text{m}$ diamond films. Combined with optical enhancements—such as high-efficiency photon collection, anti-reflection coatings, and pulsed ODMR readouts—these sensors have demonstrated sensitivities of $10\text{--}30\ \text{fT}/\sqrt{\text{Hz}}$ at room temperature in leading laboratories [4][5][11]. This performance, already validated at institutions like Harvard, MIT, and QuSpin, provides a realistic baseline for detecting metallic threats at $50\text{--}100\ \text{m}$, and larger ferromagnetic targets beyond $300\ \text{m}$ in line-of-sight (LoS) conditions.

Ambient and uncorrelated magnetic noise remain the primary barriers to real-world deployment at range. Current research focuses on AI-driven signal processing to overcome these limitations. Neural models trained on NV spectral data are being developed to isolate true magnetic signatures from powerline interference, sensor noise, and environmental drift [12][13][14]. Advanced filtering and common-mode rejection across sensor arrays have shown up to $10\times$ improvements in signal-to-noise ratio. These techniques are especially promising for detecting low-signature threats—such as concealed firearms or IEDs—at $50\text{--}80\ \text{m}$, even in semi-urban or electromagnetically noisy environments.

To extend range and reliability, QiSPS incorporates phased-array architectures with $470\text{--}700$ spatially distributed NV sensor nodes. This ongoing research effort applies coherent beamforming and spatiotemporal tracking to increase directional sensitivity, suppress background clutter, and lock onto moving or partially shielded magnetic anomalies [15][16]. Simulations and early prototypes suggest this approach can detect drones and long weapons at over $100\ \text{m}$, and track vehicles or large IEDs at $300\text{--}500\ \text{m}$ or more [17]. The phased-array design mirrors techniques from radar and sonar but applies them to the magnetic domain—pushing the frontier of passive, non-radiating detection systems. Investigation aims to close the gap between quantum-limited sensitivity and operational robustness in real-world defense settings. With continued progress in NV material science, AI-enhanced processing, and scalable sensor integration, the QiSPS platform offers a viable path to deployable magnetic threat detection at tactically relevant standoff distances. Current modeling,

confirms that detection of concealed metallic threats—from small arms to vehicle-borne IEDs—is achievable at $50\text{--}500\ \text{m}$, depending on environment and target class [18][19].

7 | FUTURE CAPABILITIES

A major evolutionary path on the QiSPS roadmap is the development of a wearable variant: the Quantum Intelligence Sensor Scout (QiSS). QiSS condenses the core quantum sensing and GPS-denied navigation functions of QiSPS into a soldier-portable form factor. The QiSS platform is designed for integration into helmet- or vest-mounted modules and should be optimized for power-efficient operation during extended dismounted missions. QiSS provides localized threat detection and secure position awareness in complex environments such as subterranean networks, urban infrastructure, or regions subjected to electronic warfare. Acting as a distributed, networked sensor node, QiSS synchronizes with both the QiSPS system and the broader Battlefield Management System (BMS), facilitating data fusion and real-time battlefield awareness.

A future capability under active investigation is the use of QiSS as a portable, non-invasive medical imaging device—functioning as a simplified, field-deployable analog to MRI technology. NV centers, due to their extreme sensitivity to magnetic fields, can detect bio-magnetic signals arising from neural, cardiac, and muscular activity. This enables high-precision monitoring of physiological functions without the need for bulky diagnostic equipment [8]. Injuries and inflammation can cause disruptions in local magnetic field patterns. NV sensors may detect such anomalies, supporting the identification of internal trauma (e.g., contusions, hemorrhaging, edema) without surgical intervention or large-scale imaging systems. Additionally, these sensors may enable microvascular monitoring, where deviations in magnetic signatures caused by altered blood flow—such as hemorrhages or occlusions—can be rapidly identified. Furthermore, NV sensors possess nanoscale thermometric capabilities. Given that infection or tissue damage often correlates with abnormal temperature profiles, the QiSS device could facilitate early detection of issues such as internal bleeding, ischemia, or infection. This would empower field medics to conduct non-invasive triage, prioritize treatment, and enable real-time assessment in austere conditions. All physiological data collected by QiSS can be securely relayed to rear-echelon medical units through the BMS, streamlining casualty management and improving medical response times. Beyond diagnostics, QiSS may support continuous physiological monitoring, tracking neural, cardiac, muscular, thermal, and vascular indicators to provide a real-time health status profile. This



allows early detection of fatigue, dehydration, exertional stress, or emerging medical conditions, enabling proactive intervention and improving mission survivability.

Additionally, research is underway to integrate neuromorphic processors—brain-inspired computing architectures—into the QiSPS and QiSS platforms. These processors offer ultra-low-power contextual data analysis and edge-based situational awareness, enhancing operational autonomy in energy-constrained environments [9][10].

Finally, the QiSPS system should be studied to support multi-agent coordination via quantum-aware swarm intelligence algorithms. This capability will allow groups of drones, autonomous vehicles, and distributed sensors to operate as a self-organizing, fault-tolerant network. These advances ensure that QiSPS and its derivatives will remain at the forefront of quantum-enabled defense capabilities through the coming decade and beyond.

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