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Quantum Sensing for Systems-Level Technologies and Applications. Protocol for an Updated Systematic Literature Review (2023–2025)

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ADMINISTRATIVE INFORMATION

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Conflicts of interest - None declared.

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Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 14 March 2026 and was last updated on 14 March 2026.

INTRODUCTION

Review question / Objective This updated systematic literature review aims to evaluate the present state, maturity, and systems-level usability of quantum sensing technologies reported between 2023 and 2025. Specifically, it addresses: (1) What is the present state of quantum sensing practice? (2) How useful are quantum sensors for systems applications? and (3) What has changed since 2022 relative to the 2018–2022 baseline review? The review focuses on experimentally demonstrated quantum sensing artifacts, subsystems, and prototypes and maps them across technology classes, application domains, integration patterns, and estimated technology readiness levels (TRLs).

Rationale Quantum sensing has progressed from laboratory demonstrations toward deployable subsystems for timing, navigation, geophysics, biomedicine, industrial monitoring, communications, and secure/networked systems. Since the authors' earlier review covered 2018–

2022, an updated synthesis is needed to determine how the field changed during 2023–2025, identify which technologies now have experimental proof at the systems level, and reassess practical usability. The review is motivated by rapid growth in publications mentioning quantum sensing, the emergence of new experimentally demonstrated sensing categories, and increasing evidence of real-world trials in areas such as cold-atom timekeeping and gravimetry, room-temperature magnetometry, and low-light imaging. A systems-oriented review is necessary because practical adoption depends not only on raw sensitivity but also on packaging, integration with classical electronics and photonics, environmental robustness, calibration, and evidence of deployment readiness. This review therefore updates the evidence base on technology maturity, integration patterns, application value, and commercialization barriers.

Condition being studied The review studies quantum sensing technologies and their systems-level applications. More specifically, it examines

implemented quantum sensing devices, prototypes, and subsystems that have been empirically demonstrated and evaluates their maturity, usability, and deployment potential across domains such as position, navigation, and timing (PNT), geophysical imaging, biomedicine, industrial/environmental monitoring, communications/security, and quantum networking.

METHODS

Search strategy Primary database searches were conducted in August 2025 and restricted to publication years 2023–2025. The review used six bibliographic databases: ProQuest, EBSCO, Springer, IEEE Xplore, Scopus, and Web of Science. To identify implementation-oriented studies relevant to the review questions, the final search query was: “quantum sensing” AND sensor* AND (prototy* OR PoC OR MVP OR device*) AND (demonstrati* OR implementati* OR empiric*). The search was limited to scholarly, peer-reviewed papers. Records were screened first by title/abstract and then by full-text eligibility assessment. Duplicate or repeated versions were removed using DOI, title, and venue metadata.

Participant or population The review population comprises scholarly publications published between 2023 and 2025 that report implemented quantum sensing devices, prototypes, proof-of-concept systems, or sensing subsystems with empirical demonstration, testing, or evaluation.

Intervention Implemented quantum sensing platforms, including nitrogen-vacancy and magnetic-resonance sensors, photonic quantum sensors, ion-trap and optical-lattice systems, superconducting and quantum-dot devices, non-Hermitian/exceptional-point sensors, optomechanical/mechanical sensors, and quantum-critical/many-body platforms.

Comparator Where reported, studies were compared with classical sensing baselines, alternative quantum sensing modalities, different demonstration settings (laboratory versus field or deployed testbed), and the authors’ prior 2018–2022 review.

Study designs to be included Experimental studies reporting implemented artifacts, prototypes, proof-of-concept devices, minimum viable products, laboratory demonstrations, field trials, and empirical evaluation papers.

Eligibility criteria Included scholarly publications (2023–2025) that explicitly address quantum sensing and a sensor or sensing subsystem and that report an implemented artifact together with empirical demonstration, testing, or evaluation. Excluded theoretical or simulation-only papers without an implemented sensing artifact, papers that mention quantum sensing only tangentially without presenting a sensing device or subsystem, non-scholarly items such as news and patents, and duplicate or repeated versions of the same work.

Information sources ProQuest, EBSCO, Springer, IEEE Xplore, Scopus, and Web of Science. The primary searches were conducted in August 2025 and restricted to publication years 2023–2025. Only scholarly, peer-reviewed sources were considered.

Main outcome(s) Main review outcomes are: (a) sensing modality and physical platform; (b) reported empirical performance metrics such as sensitivity, resolution, bandwidth, and stability; (c) demonstration setting (laboratory, field, or deployed testbed); (d) system integration features; (e) application-domain mapping; and (f) estimated technology readiness level (TRL).

Additional outcome(s) Additional outcomes include changes relative to the 2018–2022 baseline review, counts of experiment-proven technology classes, qualitative TRL distributions, integration patterns, commercialization challenges, and systems-level value propositions across major application domains.

Data management Records retrieved from all databases were exported into a unified dataset and de-duplicated using DOI, title, and venue metadata. Screening decisions are explained in the manuscript. The extracted study information is reported in structured evidence tables that record the sensing platform, empirical metrics, application domain, and TRL estimate for each included technology, enabling cross-study comparison and PRISMA reporting.

Quality assessment / Risk of bias analysis Because the included studies are heterogeneous and do not share a single outcome metric, a specific risk-of-bias tool was not applied. Instead, the strength of evidence was assessed using the estimated TRL and documentation of the experimental context, including whether results were benchmarked against classical baselines, whether end-to-end system constraints (e.g., SWaP, calibration, environmental robustness) were

reported, and whether the demonstration represents a laboratory proof-of-concept or a field-relevant trial.

Strategy of data synthesis The study is based on a descriptive synthesis. Included studies were grouped into technology classes and mapped to application domains and integration patterns. Counts of experiment-proven technologies and qualitative TRL distributions were summarized in tables. No formal meta-analysis was performed because outcomes, setups, and performance metrics are not directly comparable across sensing modalities.

Subgroup analysis Subgroup analyses were performed by technology class (NV/magnetic-resonance, photonic, ion-trap/optical-lattice, superconducting/quantum-dot, non-Hermitian/exceptional-point, optomechanical/mechanical, and quantum-critical/many-body), by application domain (PNT, geophysical imaging, biomedicine, industrial/environmental monitoring, communications/security, and quantum networking), and by demonstration setting or TRL where feasible.

Sensitivity analysis No formal quantitative sensitivity analysis was performed because no meta-analysis was performed. Robustness was assessed narratively by examining database-specific yields, deduplication effects, indexing differences, and the influence of the demonstration-focused search string and 2023 – 2025 time window on the resulting evidence base.

Language restriction Only English search terms were used.

Country(ies) involved Israel; Austria.

Other relevant information This review follows PRISMA 2020 and updates the authors' previous 2018–2022 review. The protocol was not previously registered in a public registry. The extracted evidence table and categorization files are available from the corresponding author upon reasonable request.

Keywords quantum sensing; systems applications; nitrogen-vacancy centers; photonics; optical-lattice clocks; ion traps; optomechanics; exceptional-point sensors; TRL; systematic review.

Dissemination plans Findings will be disseminated through submission of the full manuscript to a peer-reviewed journal, presentation at relevant conferences or

workshops, and sharing of extracted evidence tables and categorization files upon reasonable request to the corresponding author.

Contributions of each author

Author 1 - Boris Kantsepolsky - Author 1: Boris Kantsepolsky - Coordinated the study, designed the methodology, conceived the review, contributed to screening and synthesis, drafted the manuscript, and serves as corresponding author. Email: boriskn@mta.ac.il

Author 2 - Itzhak Aviv - Author 2: Itzhak Aviv - Conducted database work and title/abstract screening with Author 1, participated in eligibility assessment, data extraction, interpretation, and manuscript revision.

Author 3 - Ruti Gafni - Author 3: Ruti Gafni - Contributed to methodological refinement, consensus on eligibility disagreements, interpretation of findings, and critical revision of the manuscript.

Author 4 - Eran Dahan - Author 4: Eran Dahan - Contributed to systems-level framing, interpretation of results, and critical revision of the manuscript.

Author 5 - Omer Rozenblat - Author 5: Omer Rozenblat - Conducted database work, contributed to data extraction, screening, and synthesis.