

Supplementary Material

Multi-Source Data Fusion for Underwater Geophysical Field Matching Navigation: A Systematic Review of Methodologies, Challenges, and Future Trends

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Study Classification and Evidence Mapping

The literature search strategy was constructed from three complementary concept groups: (1) navigation objects and application scenarios, (2) fusion methods, and (3) geophysical-field data types. These groups were used as Boolean search dimensions rather than mutually exclusive study categories. Consequently, a single article may appear in more than one table or subgroup when it contributes to more than one analytical dimension.

Tables S2–S4 provide the study-level evidence mapping requested by the reviewer. Reference numbers correspond to the numbered reference list in the main manuscript. Reporting guidelines, dataset descriptions, reference-field documents, review articles, and generic methodological foundations are retained in the tables as supporting references where they contribute to the literature search, taxonomy, preprocessing analysis, benchmark design, or discussion. Because the three dimensions overlap, the entries in Tables S2–S4 should not be summed to infer the total number of included studies. The completed PRISMA 2020 Checklist is submitted separately as Supplementary Table S1.

Table S2: Mapping of cited and analyzed studies according to navigation objects and application scenarios.

Navigation object or application scenario	References in the main manuscript	Role in the review
General underwater/AUV navigation, localization, integrated navigation, and SLAM	[1]–[4], [58]–[60], [67], [90]–[94], [98]–[100]	Defines the broader underwater-navigation context, multisensor integration framework, engineering constraints, and competitive baselines.
Terrain-aided and bathymetry-aided underwater navigation	[5], [6], [10], [11], [33], [51], [52], [75], [84]–[87], [95]	Supports the analysis of terrain-map matching, bathymetric constraints, probabilistic localization, robustness, and closed-loop navigation.
Gravity-aided and gravity-gradient-aided navigation	[7], [8], [12], [13], [20], [22], [25]–[27], [30], [38], [52], [53], [88]	Supports gravity-map matching, matching-area selection, confidence assessment, filtering, and long-range drift correction.

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Table S2 continued

Navigation object or application scenario	References in the main manuscript	Role in the review
Geomagnetic and magnetic-anomaly navigation	[9], [16], [23], [28], [29], [43], [44], [89], [96], [97], [101]	Supports magnetic-map preparation, information-aware guidance, learning-based localization, robust matching, and dataset-performance analysis.
Multi-field or hybrid geophysical navigation	[10], [18], [19], [21], [56], [58], [94]	Supports cooperative use of terrain, gravity, geomagnetic, inertial, acoustic, and other complementary observations.
Marine geophysical mapping and reference-map construction supporting navigation	[14], [15], [17], [24], [34]–[50], [54], [55], [57], [61]–[66]	Provides evidence on heterogeneous map construction, interpolation, reference-field removal, uncertainty, inversion, and map refinement.
Supporting review, reporting, feature-extraction, and learning foundations	[31], [32], [68]–[83]	Supports systematic-review reporting, feature taxonomy, handcrafted descriptors, lightweight networks, attention mechanisms, and cross-modal fusion analysis.

Table S3: Mapping of cited and analyzed studies according to fusion methods and analytical roles.

Fusion-method category	References in the main manuscript	Role in the review
Review, reporting, taxonomy, and benchmark-supporting studies	[1]–[3], [31]–[33], [59], [75], [82], [98], [99]	Supports the systematic-review protocol, scope definition, three-level taxonomy, open-issue synthesis, and comparison with related reviews.

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Table S3 continued

Fusion-method category	References in the main manuscript	Role in the review
Preprocessing, reference-field modeling, dataset construction, and uncertainty characterization	[23], [35]–[37], [40]–[50], [54], [55], [101]	Supports coordinate and datum alignment, main-field removal, global map selection, uncertainty layers, and data-quality analysis.
Map-level fusion and physically constrained map construction	[14], [15], [17], [18], [24], [34], [39], [57], [61]–[66]	Covers spatial weighting, interpolation, wavelet fusion, map refinement, neural reconstruction, equivalent-source modeling, and joint inversion.
Feature-level fusion based on handcrafted descriptors and suitability measures	[20], [25], [26], [28], [30], [53], [68]–[74], [96]	Covers texture, gradient, entropy, local descriptors, matching-area selection, information measures, and contour-based matching.
Feature-level fusion based on learning and attention mechanisms	[9], [15], [24], [29], [61], [62], [76]–[81], [83], [97]	Covers random forests, neural map refinement, lightweight convolutional backbones, attention, Transformers, and learning-enhanced matching.
Decision-level probabilistic fusion, filtering, weighting, and sequence matching	[5]–[8], [10]–[13], [16], [19], [21], [22], [27], [38], [52], [56], [60], [84]–[89], [95]	Covers KF/EKF/UKF, PF/PMF/RBPF, Viterbi and probabilistic matching, dynamic weighting, robust gating, and state-update strategies.
Factor-graph, smoothing, cooperative localization, and tightly coupled multisensor fusion	[58], [67], [90]–[94]	Supports globally consistent estimation, sliding-window optimization, graph factors, cooperative localization, and underwater SLAM.

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Table S3 continued

Fusion-method category	References in the main manuscript	Role in the review
General AUV engineering and competitive navigation frameworks	[4], [51], [100]	Provides supporting evidence on platform operation, attitude and heading dynamics, path planning, and deployment-related constraints.

Table S4: Mapping of cited and analyzed studies according to geophysical-field data types.

Geophysical-field data type	References in the main manuscript	Role in the review
Seafloor terrain and bathymetry	[5], [6], [10], [11], [15], [33], [35]–[37], [51], [52], [62], [75], [84]–[87], [94], [95], [100]	Supports terrain-map construction, sonar or depth observations, terrain matching, bathymetric prediction, and terrain-aided state estimation.
Gravity anomaly and gravity-gradient data	[7], [8], [10], [12]–[15], [17]–[22], [24]–[27], [30], [34], [38], [39], [45]–[50], [52], [53], [56], [57], [61], [62], [64], [66], [88]	Supports marine gravity-map generation, gravity matching, gravity-gradient features, uncertainty analysis, inversion, and gravity-aided navigation.
Geomagnetic and magnetic-anomaly data	[9], [16], [18], [19], [21], [23], [28], [29], [40]–[44], [54]–[56], [63], [66], [73], [74], [89], [94], [96], [97], [101]	Supports main-field removal, magnetic-anomaly mapping, feature extraction, information-aware guidance, geomagnetic matching, and magnetic navigation.
Multiple or cross-coupled geophysical fields	[10], [18], [19], [21], [56], [62], [66], [94]	Supports bathymetry-gravity, gravity-geomagnetism, gravity-bathymetry, and broader multi-sensor or cross-field cooperative frameworks.

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Table S4 continued

Geophysical-field data type	References in the main manuscript	Role in the review
Non-field-specific navigation, fusion, reporting, and algorithmic foundations	[1]–[4], [31], [32], [58]–[60], [65], [67]–[72], [75]–[83], [90]–[93], [98]–[100]	Provides supporting methods and context without being restricted to one terrain, gravity, or geomagnetic data type.

Coding Notes

- A reference may appear in multiple rows or tables because the coding dimensions are complementary and non-exclusive.
- The method-level classification follows the principal contribution discussed in the main manuscript. Secondary relevance is retained where a study contributes to more than one fusion stage.
- PRISMA guidance, public datasets, global reference-field documents, review papers, and generic feature or learning foundations are identified as supporting references rather than primary underwater navigation methods.
- The reference numbers in this document must remain synchronized with the final numbered reference list in the main manuscript.