Feasibility Of a Multi-Modal Sensing Guidewire for Tissue Interaction Awareness in Bronchoscopic Lung Cancer Intervention: A Conceptual Architecture and Validation Roadmap

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***Abstract*—Bronchoscopic access to peripheral pulmonary lesions has been transformed by navigation, robotic, and imaging-assisted platforms, yet the physical interaction between an instrument tip and airway tissue remains difficult to quantify directly. Conventional guidewires provide push ability, torque transmission, and mechanical steering, but generally do not return a direct quantitative signal describing tissue interaction. This paper presents a literature-grounded feasibility framework that reimagines the guidewire as a multi-modal sensing platform rather than a purely mechanical component. Four complementary sensing channels—force, localized pressure, electrical impedance, and temperature—are proposed within a guidewire-centred architecture. The methodology comprises channel calibration and signal conditioning, temporal synchronization, feature extraction, lightweight edge-assisted sensor fusion, confidence estimation, and human-in-the-loop clinician feedback. Artificial intelligence is deliberately positioned as a supporting interpretation layer for procedural interaction states rather than as an autonomous cancer-diagnosis mechanism. The study analyses the principal mechanical, electrical, miniaturization, packaging, safety, and manufacturing constraints and defines a staged validation pathway from component calibration and bench testing through tissue-mimicking phantom evaluation, AI validation, preclinical feasibility, and eventual clinical feasibility. No prototype measurements or clinical diagnostic performance are claimed in the present work. The principal outcome is a coherent, experimentally testable architecture and validation roadmap that identifies how quantitative instrument–tissue information could complement existing bronchoscopic navigation while preserving clinician control. Advanced technologies are retained as future extensions outside the present scope.**

***Index Terms*—bronchoscopic intervention, electrical impedance sensing, lung cancer, multi-modal sensing, sensor fusion, smart guidewire, tissue-interaction sensing.**
Manuscript status: Conceptual engineering feasibility study. No prototype performance, clinical efficacy, diagnostic accuracy, or patient outcome is claimed.

I. INTRODUCTION

Lung cancer remains one of the greatest contributors to the global cancer burden. Lung cancer continues to be the most common cause of cancer death worldwide [1], with an estimated 2.5 million new cases and 1.8 million deaths in 2022 by the World Health Organization. Lung cancer is one of the most common cancers diagnosed and the leading cause of cancer death according to recent global estimates [2]. The clinical impact of having reliable methods to evaluate peripheral pulmonary lesions is large since early detection increases the number of treatment options.

Bronchoscopy has progressed from conventional visual inspection to image-guided and navigation-assisted intervention such as electromagnetic navigation, virtual bronchoscopic navigation, radial endobronchial ultrasound, ultrathin bronchoscopy, and robotic-assisted bronchoscopy.

These techniques have improved accessibility of peripheral lesions and shown useful diagnostic performance [3]– [5]. However, better localization does not automatically provide direct quantitative information of what is going on at the instrument–tissue interface.

A conventional guidewire provides mechanical support, push, torque transmission and steering.

Contact and resistance are inferred by the operator from tactile cues, instrument behavior, imaging and experience with the procedure. Such information is clinically useful but is mostly qualitative. The resulting engineering opportunity is to enhance the guidewire with small sensing elements that are able to report the measurable information of interaction without disturbing the fundamental human-controlled workflow.

The study presents one question: How to turn a standard bronchoscopic guidewire into an intelligent sensing platform that provides real-time awareness of tissue interaction and AI-assisted decision support during lung cancer intervention? This paper argues that such a transformation is technically feasible using sensing components that already exist, and that the binding constraint is not sensor availability but mechanical compatibility: the design succeeds only if instrumentation leaves guidewire handling essentially unchanged.
And all that follows Is built around defending that claim. The proposed answer here is a feasibility-oriented architecture based on four complementary sensing modalities, synchronized processing, conservative AI-assisted fusion and clinician-facing feedback.

The contribution is intentionally narrow. Main research focus is on a guide-wire centric sensing architecture with underlying layers of AI, edge processing and lightweight monitoring. Some of the components are left as future extensions and are not considered as implemented components, they are listed in full in Appendix A: large cloud infrastructures, block chain, federated learning, 5G/6G, EHR integration, predictive maintenance, and digital-twin implementation.

The paper is mainly organized as follows. Section II is a review of the clinical and technical literature. Section III presents the research gap and objectives. The proposed architecture is shown in Section IV and the sensor-fusion workflow in Section V. Section VI discusses the engineering feasibility, Section VII the monitoring layer and Section VIII the staged validation methodology. Section IX gives a comparative analysis, Section X presents the limitations, and Section XI concludes.

II. CLINICAL BACKGROUND AND RELATED WORK

A. Peripheral Pulmonary Lesions

Peripheral pulmonary lesions are difficult to access because they may be deep within branching airway structures and may be small relative to surrounding anatomy Navigation techniques improve access but diagnostic performance still depends on lesion size, bronchus sign, location, sampling method and operator technique [3]– [5]. The clinical challenge is thus twofold: to reach a target and then to maintain appropriate instrument–tissue interaction while manipulating and sampling.

B. Navigation and Robotic Bronchoscopy

Electromagnetic navigation bronchoscopy can guide instruments to peripheral lesions. In a systematic review and meta-analysis, the pooled sensitivity for malignancy was reported to be around 77% with a pneumothorax risk of nearly 2% in the literature analyzed [5].
In general, navigation bronchoscopy has been shown to have an improved diagnostic yield compared to non-navigation [3].
Recent meta-analytic literature reports pooled diagnostic yields in the approximate 80–84% range depending on study population and inclusion criteria [4], with robotic-assisted bronchoscopy further improving catheter control and stability. These results demonstrate the importance of navigation and instrument control, but do not address the separate problem of direct guidewire-level tissue-interaction sensing.

C. Artificial Intelligence in Bronchoscopy

Artificial intelligence is under increasing investigation across bronchoscopic applications.
A 2025 systematic review identified studies spanning airway anatomy, navigation, endobronchial ultrasound, and diagnostic evaluation, while also highlighting a need for stronger implementation evidence [6]. A separate review similarly stressed external validation and real-world workflow integration [7]. Both observations support the conservative role adopted in this work: AI interprets synchronized sensor information and supports clinician judgment; it does not issue autonomous diagnoses.

D. Force and Smart-Catheter Sensing

Force sensing has drawn sustained attention in minimally invasive surgery because the loss of direct tactile sensation affects both navigation and tissue manipulation. Reviews describe direct and indirect approaches and emphasize trade-offs among sensor integration, flexibility, sterilization, and instrument size [8], [9]. The same constraint recurs throughout the smart-catheter literature: embedding several functions in a flexible miniature body, without sacrificing the flexibility that makes the device usable, remains the limiting difficulty [9].

E. Limitations of Passive Guidewires

Five limitations follow from the passive design of conventional guidewires:

- Direct quantitative force at the guidewire–tissue interface is not inherently available to the operator.
- Localized contact pressure is never continuously reported as an independent measurement.
- Imaging supplies anatomical context but does not measure mechanical interaction at the guidewire tip.
- A single tactile or mechanical cue can be ambiguous, since friction, curvature, and tissue contact may all produce similar resistance changes.
- Existing bronchoscopic AI research concentrates on image interpretation, navigation, endobronchial ultrasound, and diagnostic assistance, leaving guidewire-embedded multi-modal sensing largely unexplored [6], [7].

III. RESEARCH GAP AND OBJECTIVES

A. Research Gap

The literature demonstrates substantial progress in bronchoscopic navigation, robotic control, AI-assisted interpretation, and smart-catheter sensing. These capabilities have developed as largely separate technological tracks. The engineering opportunity addressed here is their integration: compact force, pressure, electrical impedance, and temperature sensing with in a bronchoscopic guidewire-centred architecture, coupled to low-latency sensor fusion for procedural interaction awareness. The novelty lies in the integrated architecture and validation methodology and not in any claim that the individual sensing modalities are themselves new.

The literature reviewed for this study did not identify an established guidewire-centred framework combining these four sensing domains with synchronized AI-assisted procedural-state estimation for bronchoscopic intervention. This bounded statement is preferred to the broader and unverifiable claim that no related technology exists.

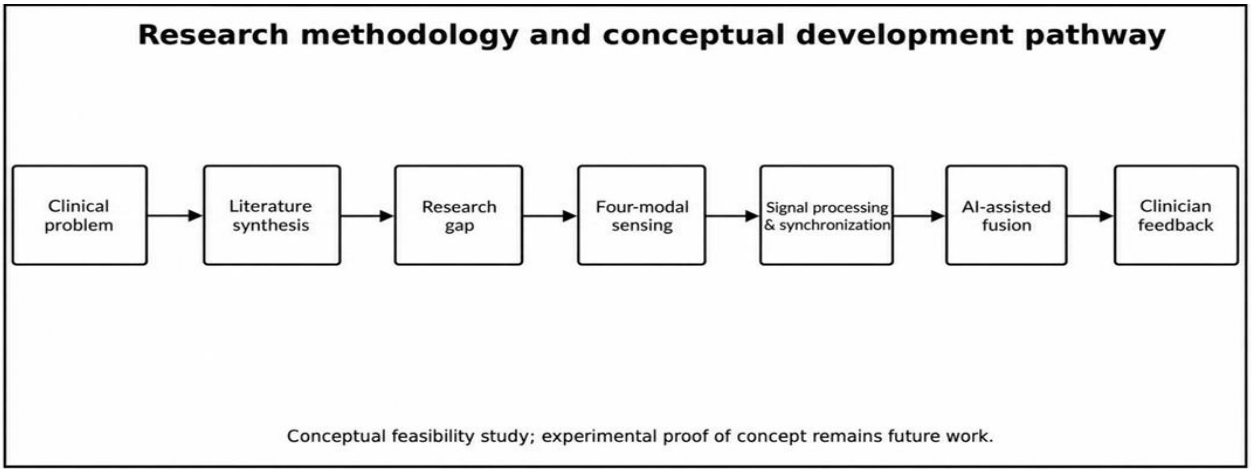

Fig. 1. Research methodology used to derive the proposed feasibility framework. Experimental proof of concept remains future work.

B. Objectives and Contributions

The study pursues six objectives:

- Develop a conceptual architecture that converts a passive bronchoscopic guidewire into a sensing-enabled intelligent instrument.
- Integrate force, pressure, electrical impedance, and temperature sensing while preserving the mechanical characteristics navigation requires.
- Develop an AI-assisted multi-modal sensor-fusion workflow for procedural interaction-state

estimation.

- Provide interpretable, human-in-the-loop decision support with explicit uncertainty handling.
- Evaluate mechanical, electrical, computational, packaging, safety, and manufacturing feasibility at the design level.
- Define a staged pathway from laboratory prototype development toward future clinical feasibility.

Six principal contributions follow: intelligent guidewire architecture; a four-modality sensing framework; an AI-assisted sensor-fusion methodology, a human-in-the-loop decision-support model, a light weight local monitoring layer, and a prototype-to-clinical translation roadmap. Fig. 1 summarizes the methodology by which the framework was derived.

IV. PROPOSED MULTI-MODAL SMART GUIDEWIRE ARCHITECTURE

A. System Decomposition

The proposed system divides into a distal sensing region, flexible interconnects, a proximal acquisition and processing unit, and a clinician-facing interface. This distributed arrangement attacks the central miniaturization problem directly: sensing elements and conductors must stay small and flexible at the distal end, whereas bulky power-management; acquisition, processing, and communication component scan remain proximal wherever practical. Exact dimensions, battery capacity, processor selection, and wireless protocol are treated as prototype-level decisions, not finalized specifications.

The functional data path runs as follows: tissue interaction → sensor acquisition → calibration and filtering → temporal synchronization → feature extraction → multi-modal fusion → confidence estimation → clinician feedback.

Procedural logging may retain compact features and event records instead of continuously transmitting every raw sample. Fig. 2 shows the resulting separation of distal sensing from proximal electronics.

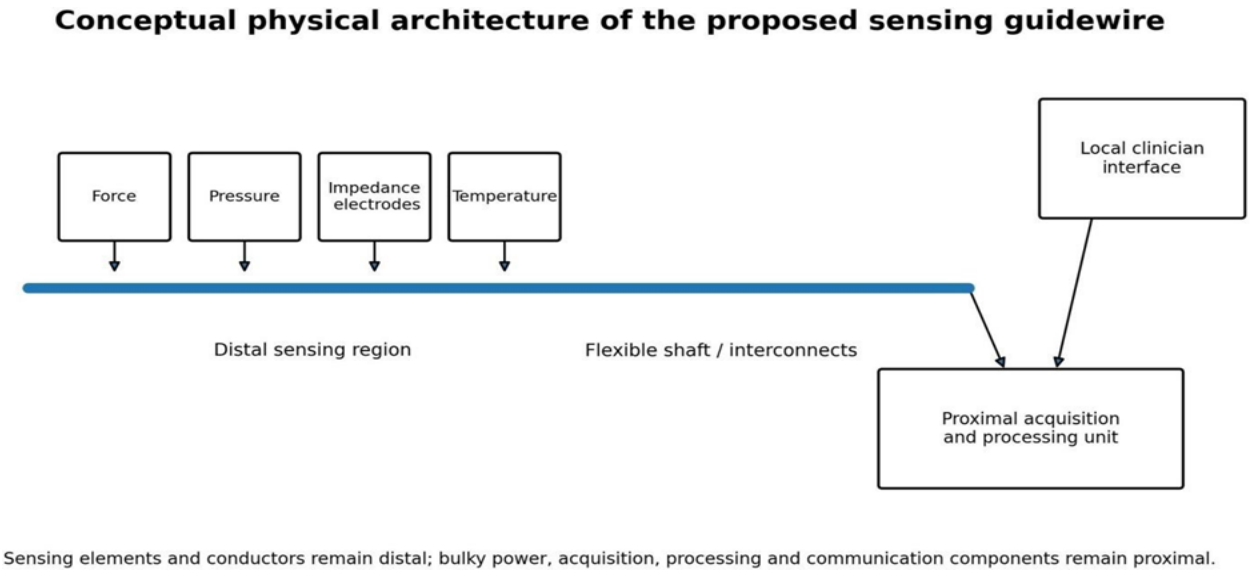

Fig. 2. Conceptual physical architecture. The illustration is schematic and not to scale; it shows the intended separation of distal sensing and proximal electronics.

B. Force Sensing

The force-sensing subsystem estimates mechanical loading transmitted through the guidewire during advancement, withdrawal, bending, and contact. Candidate implementations include miniature strain-based or micro electro mechanical structures. Useful features may include mean force, peak force, rate of change, and cumulative exposure. No numerical force threshold is proposed as a clinical safety limit, because such limits demand controlled experimental and clinical evidence that this study does not provide.

C. Pressure Sensing

Pressure sensing complements force measurement by giving a more localized picture of contact or loading. Together, force and pressure may help separate distributed resistance from a localized contact event. Packaging must shield the sensing element from moisture and mechanical damage while preserving the interface that makes meaningful measurement possible.

D. Electrical Impedance Sensing

Electrical impedance introduces a tissue-related measurement domain physically distinct from mechanical loading. A miniature electrode arrangement may acquire impedance magnitude and phase across a selected frequency range. Within this framework, impedance functions as an auxiliary tissue-interface signature, not a direct cancer detector. Electrode geometry, contact pressure, excitation conditions, frequency selection, fluid environment, and motion artifacts all require experimental characterization.

E. Temperature Sensing

Temperature enters the design mainly as contextual information and as a possible compensation variable for temperature-dependent sensor drift. A miniature temperature element may monitor local thermal changes during the procedure. It is not proposed as an independent malignancy detector.

V. AI-ASSISTED SENSOR FUSION

Each channel is first calibrated and quality-checked. Signals are then filtered and aligned to a common temporal reference, since the four modalities differ in response characteristics and sampling rates. Features are extracted over short windows and passed to a lightweight fusion model. A conceptual feature vector takes the form

$$X(t)=[F, dF/dt, P, dP/dt, Z, \Delta Z, T, dT/dt] \quad (1)$$

where F and P denote force and pressure features, Z an impedance feature, and T temperature. The derivative and change terms capture short-term dynamics. The estimated interaction state can be written conceptually as $\hat{Y} = f\theta(X)$, with $f\theta$ a learned model. These expressions define the intended data pathway; they are not experimentally validated predictive equations.

A. Procedural State Classes

To keep the work experimentally defensible, the initial AI target should be procedural, not histological. Candidate classes are low interaction, increasing contact, high mechanical interaction, uncertain state, and sensor anomaly. Framing the problem this way avoids an unsupported leap from raw sensor measurements to a cancer-subtype diagnosis.

B. Confidence-Aware Fusion

The design does not assume equal contribution at each instant, the four modalities are complementary.

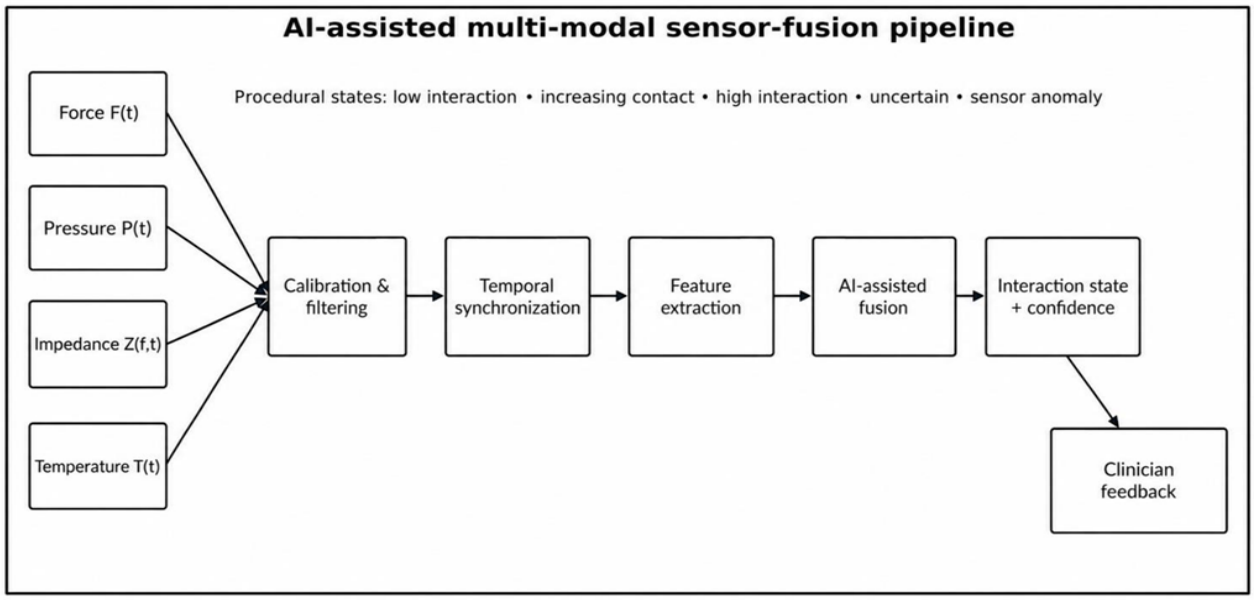

Fig.3.AI-assisted multi-modal sensor-fusion pipeline for procedural interaction-state estimation.

Force and pressure may bear stronger information during mechanical contact, Impedance may become more informative once contact is established, temperature may give context or compensation.
Therefore, signal quality indicators (saturation, electrode continuity, contact stability, missing data, implausible temperature values) should be transmitted along with the physical measurements.

C. Human-in-the-Loop Decision Support

The clinician-facing interface should present sensor trends, an interaction state, a confidence indicator, and warnings—never autonomous commands. Interface design and any embedded software would fall under established usability-engineering and software-life cycle standards [17], [18], and early-stage clinical evaluation of such decision support has its own reporting guideline [21]. When channels disagree or signal quality drops below an acceptable level, the system must indicate uncertainty explicitly. The clinician retains responsibility for guidewire manipulation, sampling, withdrawal, and every clinical decision. Fig. 3 shows the complete pipeline, from the four raw channels through to clinician feedback.

VI. ENGINEERING FEASIBILITY

The governing engineering constraint is blunt: sensing capability must be added without degrading the mechanical characteristics that make a guidewire useful in the first place. Table I lists requirements to be verified, not achievements already demonstrated. Each row is anchored to the normative standard that would govern its verification, covering biological evaluation [10], risk management [11], electrical safety and electromagnetic compatibility [12], [13], guidewire-specific requirements [14], and sterilization [15], [16].

TABLE I Engineering Requirements and Proposed Verification Methods

Requirement	Design intent	Future verification
Mechanical	Preserve flexibility, push ability, torque response, and distal manoeuvrability.	Bending, insertion, torque, and fatigue tests [14]
Dimensional	Minimize distal volume and abrupt stiffness transitions.	CAD measurement and mechanical comparison [14]
Sensing	Provide repeatable force, pressure, impedance, and temperature signals.	Calibration, drift, repeatability, and cross-sensitivity tests
Electrical	Maintain isolation, low noise, and stable acquisition.	Isolation, noise, and cross-talk tests [12],[13]
Packaging	Protect sensing elements without impairing flexibility.	Leakage, fatigue, encapsulation, and fluid-exposure tests
Power	Support low-power acquisition and local Inference	Power budget and endurance measurement
Biocompatibility	Use materials appropriate to the intended clinical pathway.	Material characterization and ISO10993 assessment [10]
Sterilization	Maintain sensing and mechanical performance after the intended process.	Pre/post-process characterization [15],[16]
Safety	Sensing failure must not prevent normal guidewire handling or withdrawal.	Failure-mode analysis and fail-safe tests [11]

A.Miniaturization and Packaging

Miniaturization presents the most immediate physical feasibility challenge. The architecture therefore keeps large processors, batteries, and communication modules away from the distal tip. The distal region is reserved for sensing elements and flexible conductors, while processing and power management stay proximal. This choice does not eliminate the miniaturization problem. It redistributes the problem and opens a concrete engineering path for subsequent prototype work.

B.Mechanical Interaction Model

For design-level analysis, guidewire–tissue interaction can be represented as a sum of loading components:

$$F_{total}=F_{axial}+F_{lateral}+F_{friction} \quad (2)$$

Where F_{axial} represents insertion-related loading, $F_{lateral}$ contact-related loading, and $F_{friction}$ there distance associated with interaction along the airway wall. Equation (2) is a simplified engineering representation, not a complete biomechanical model.

VII. LIGHTWEIGHT MONITORING AND CONNECTIVITY

The monitoring layer is intentionally lightweight. Time-sensitive signal conditioning, synchronization, and interaction-state estimation should stay local or proximal to the guidewire, so that the system never depends on continuous external connectivity. A local workstation or display may receive compact features, state estimates, confidence values, and event records. Connectivity therefore acts as a supporting function and forms no part of the core novelty.

A local monitoring interface may display the current interaction state, force and pressure trends, impedance quality, temperature status, confidence, and event history. If processing or connectivity becomes unavailable, the system must preserve normal clinician control. Large cloud architectures, remote monitoring ecosystems, and hospital-system integration fall outside the current scope.

VIII. VALIDATION METHODOLOGY AND PROTOTYPE ROADMAP

Because this study stops at the design stage, its proper research output is a testable validation pathway, not a fabricated performance result. The sequence below is arranged to retire technical risk progressively, and each stage should carry predefined exit criteria before the next begins.

A. Staged Pathway

- Stage 1 — Concept and CAD/simulation: verify dimensional feasibility, stiffness transitions, interconnect routing, and basic mechanical behaviour.
- Stage2—Individual sensor modules: calibrate force, pressure, impedance, and temperature channels against appropriate reference standards.
- Stage3—Integrated bench prototype: assess signal quality, synchronisation, cross-talk, mechanical compatibility, and failure behaviour.
- Stage4—Tissue-mimicking phantom: vary mechanical and electrical properties to test whether sensor combinations yield stable procedural signatures.
- Stage 5 — AI validation: use independent datasets and evaluate accuracy, precision, recall, specificity, F1-score, calibration, and robustness.
- Stage6—Preclinical feasibility: if justified and approved, assess navigation, tissue interaction, sensor stability, biocompatibility, and safety.
- Stage 7 — Clinical feasibility: after regulatory and ethical approval, evaluate safety, workflow integration, sensor functionality, and clinical usefulness.

Fig. 4 summarizes the seven stages and their order. A practical prototype should first demonstrate that sensing does not compromise basic guidewire behaviour. Only after that threshold is cleared should more advanced clinical functions be considered.

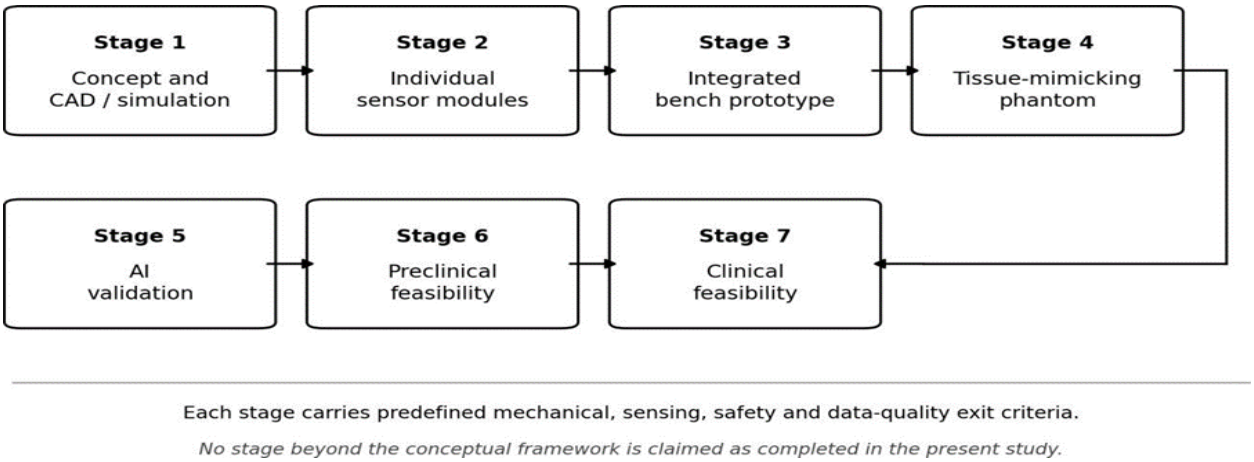

Fig.4.Proposed staged validation and translation roadmap. No stage beyond the conceptual framework is claimed as completed.

B. Validation Metrics

Mechanical evaluation should cover bending stiffness, insertion force, torque response, tip stability, and fatigue. Sensor evaluation should cover sensitivity, resolution, hysteresis, repeatability, drift, response time, frequency response for impedance, and signal-to-noise ratio. AI evaluation should use held-out data and report multiple metrics, since accuracy alone is misleading on imbalanced procedural classes; reporting should follow an established prediction-model guideline [20]. The relationship between interaction-state predictions and clinically meaningful outcomes must be established experimentally, never assumed.

C. Data and Experimental Controls

Future experiments should separate training, validation, and testing data at the subject or experiment level to reduce temporal and procedural leakage [20]. Phantom experiments should include repeated trials across differing mechanical and electrical conditions, and sensor failure or missing-channel conditions should be represented explicitly in the dataset rather than discarded.

IX. COMPARATIVE ANALYSIS AND DISCUSSION

A.Architecture-Level Findings

The literature synthesis and engineering decomposition together support the feasibility of studying a guidewire-centred multi-modal sensing architecture. At the design level, the four selected modalities address different information domains: force captures transmitted mechanical loading; pressure adds localized contact information; impedance contributes a tissue-interface electrical signature; and temperature supplies context plus possible compensation. Their combination therefore carries more meaning than four independent diagnostic sensors would. Table II situates the proposal against existing approaches.

TABLE II Architectural Comparison of the Proposed Framework

Capability	Conventional guidewire	Navigation bronchoscopy	Robotic bronchoscopy	Proposed guidewire
Mechanical navigation	Yes	Yes	Yes	Yes
Guidewire-level force sensing	No	Not inherent	Not inherent	Proposed
Localized pressure sensing	No	Not inherent	Not inherent	Proposed
Electrical impedance sensing	No	No	No	Proposed
Temperature sensing	No	No	No	Proposed
Multi-modal sensor fusion	No	Limited	Limited	Proposed
AI-assisted decision support	No	Emerging	Emerging	Proposed
Human-in-the-loop control	Yes	Yes	Yes	Yes

B.Alternative Approaches and Anticipated Objections

A proposal of this kind invites four reasonable objections, and the framework is stronger for meeting them directly.

First, if robotic bronchoscopy already delivers superior catheter control and stability [4], why instrument the guidewire at all? The answer is that robotic platforms solve positioning, not measurement. Reported pooled diagnostic yields describe where the instrument goes, not what it encounters on arrival. A robotic platform and an instrumented guidewire address different variables, and the two are complementary rather than competing.

Second, four modalities may be more than the problem requires, force sensing alone might carry most of the useful information. This objection has real force, and the honest answer is that the question is empirical. The argument for redundancy is that any single mechanical cue is ambiguous, since friction, curvature, and genuine tissue contact can all produce similar resistance. Stage 4 should therefore be designed to test channel contribution explicitly, and the architecture should be prepared to discard any modality that fails to earn its place. A four-channel design that cannot demonstrate the value of all four channels should become a two-channel design.

Third, impedance measure data guidewire tip may bed ominated by contact artifacts rather than tissue properties. This is the most serious technical risk in the proposal. It is there as on impedance is positioned as an auxiliary interface signature and never as a diagnostic output, and the reason Stage 4 varies electrical properties independently of mechanical ones. If impedance proves inseparable from contact condition, that finding is itself a useful result and should be reported as such.

Fourth, and most fundamentally, added instrumentation may degrade guidewire mechanics by more than the recovered information is worth. This objection cannot be dismissed, because it targets the central premise. The response is procedural: mechanical non-inferiority is treated as a Stage3 exit criterion rather than as an outcome to be measured afterward if an instrumented guidewire performs worse than a conventional one, the concept fails on its own merits, and no subsequent sensing performance can compensate.

X. LIMITATIONS

The proposed system remains at the design stage and therefore establishes no clinical efficacy, diagnostic accuracy, or patient benefit. Miniaturization may alter guide wire mechanics in ways this analysis cannot predict. Force and pressure measurements can be confounded by friction, curvature, operator manipulation, and packaging. Impedance measurements depend on electrode configuration, contact quality, excitation conditions, frequency, fluid environment, and tissue heterogeneity. Temperature measurements may be influenced by the surrounding environment.

AI performance will hinge on dataset size, labeling quality, class definitions, missing-data handling, and external validation [20], [22]. The relationship between sensor patterns and clinically meaningful tissue states must be demonstrated experimentally. Biocompatibility [10], sterilization [15], [16], electrical safety [12], [13], software lifecycle control [17], human factors [18], manufacturing quality management [19], and the overarching risk-management process [11] must all be established before any clinical use.

These limitations define the immediate research agenda. The next stage should prioritize measurement credibility and mechanical compatibility over the addition of further technologies.

XI. CONCLUSION

This paper has presented a focused, literature-grounded feasibility framework for transforming a conventional bronchoscopic guidewire into a multi-modal sensing platform for real-time tissue-interaction awareness. The central proposal combines force, pressure, electrical impedance, and temperature sensing with synchronized acquisition, lightweight AI-assisted fusion, and human-in-the-loop feedback.

The distributed architecture addresses a central feasibility concern by separating distal sensing from proximal processing and power management. The study also defines engineering requirements, a simplified interaction-state model, and a staged validation methodology that converts the idea into an experimentally test able research programme. The paper claims no autonomous cancer diagnosis, no clinical efficacy, and no completed prototype performance.

The principal research opportunity is to determine experimentally whether a compact four-modality sensing architecture can deliver reliable and useful quantitative information at the instrument–tissue interface without compromising guidewire mechanics. Should subsequently bench and phantom studies support that premise, the framework can advance toward prototype and clinical feasibility evaluation.

Appendix A.
ADVANCED EXTENSIONS BEYOND THE CURRENT SCOPE

- This study concentrates on the feasibility of a multi-modal sensing guidewire. The technologies below are retained as long-term extensions to be revisited after the core architecture is validated. None are implemented features of the present work.
- Digital-twin-enabled procedural visualization synchronizing CT-derived anatomy, guidewire position, and sensor streams.
- Federated learning for privacy-preserving multi-centre AI development once suitable datasets exists.
- Blockchain for tamper-evident procedural records and audit trails where justified.

- 5G/6G connectivity for remote expert consultation and tele-procedural collaboration.
- Hospital information system and EHR interoperability after clinical workflow requirements are established.
- Cloud-based population analytics using appropriately anonymised procedural data.
- Predictive maintenance for reusable or modular intelligent devices.
- Explainable AI and uncertainty visualisation for future clinical interfaces.
- Flexible electronics and further sensor miniaturisation.
- Haptic feedback and semi-autonomous navigation assistance under physician supervision.

DECLARATIONS

Data availability—No new experimental dataset was generated or analyzed in this conceptual study. The scientific basis derives from the cited literature.

Ethics— This conceptual study involves no human participants, animal experiments, or identifiable patient data, no ethical approval or informed consent was required.

Conflict of interest— The authors declare no known competing financial interests or personal relationships that could have influenced this work.

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