Paper 016

Differentiable Finite-Element Geometry Search for Electrostatic Null Experiments

Optimizing apparatus for discrimination rather than maximum residual force

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Abstract

The finite-element discrimination paper proposes scoring geometries by how well mechanisms separate under controls. This paper makes that idea algorithmic. It frames geometry design as a constrained optimization problem: maximize mechanism separability while bounding ordinary artifacts, manufacturability cost, voltage stress, leakage risk, and balance compatibility. Differentiable or surrogate-assisted FEM becomes a design engine for falsification-first laboratory hardware.

Status. Draft manuscript for review and revision. This paper is not an empirical claim of new physics or field-ready technology. It is a structured proposal, theory note, protocol, or application architecture intended to be auditable, falsifiable, and publishable with source.

Contents

1 Problem

Hand-designed capacitor geometries are slow to iterate and often optimize the wrong objective. A geometry with a large asymmetric field may also amplify leakage, thermal drift, or EHD artifacts. The problem is to search geometries whose transformation signatures differ across mechanisms while staying practical to fabricate and measure.

2 Model

A geometry G is mapped by a solver to a feature vector containing Maxwell stress, thermal proxy, leakage proxy, scalar proxy, boundary proxy, and observability metrics. The objective is a robust lower bound on pairwise signature distance after nuisance perturbations.

$$\mathcal{J}(G) = D(G) - \lambda_1 A_{\mathrm{artifact}}(G) - \lambda_2 C_{\mathrm{fab}}(G) - \lambda_3 R_{\mathrm{breakdown}}(G),$$
$$D(G) = \min_{m \neq n} \min_{\delta \in \Delta} \|s_m(G+\delta) - s_n(G+\delta)\|_{\Sigma^{-1}}.$$

3 Claims

1. **Claim 1.** Geometry search should optimize discrimination and artifact suppression, not raw predicted force.
2. **Claim 2.** A surrogate model trained on FEM outputs can pre-screen designs before expensive high-fidelity solves.
3. **Claim 3.** Robust optimization over manufacturing perturbations prevents false separation caused by idealized CAD.
4. **Claim 4.** The same design machinery can propose negative-control geometries that deliberately amplify known artifacts.

4 Evidence Plan

The evidence plan compares random search, human baseline geometries, and surrogate-assisted optimization on canonical test families. Each selected design is evaluated under pressure, polarity, inversion, shielding, edge smoothing, and scale controls. The expected result is a ranked atlas of buildable devices, including artifact amplifiers and strict nulls.

5 JMP0X1B Implementation Surface

The JMP0X1B implementation should treat solvers as effectful actors with deterministic manifests: geometry digest in, result digest out. Optimization traces must be reproducible so reviewers can detect objective hacking.

Illustrative JMP0X1B-style contract

```
actor GeometrySearch {
    effect FEM
    fn propose(seed: DesignSeed) -> Geometry
    fn evaluate(g: Geometry) -> SignatureVector effects{FEM, Units}
    fn accept(g: Geometry, score: Score) -> TraceEvent effects{Audit}
}
```

6 Release And Review Plan

Release geometry seeds, objective definitions, solver settings, mesh convergence logs, and failed designs. Failed designs are important because they reveal which artifacts dominate the search space.

7 Open Questions

- Which surrogate uncertainty metric is conservative enough for physical apparatus design?
- Can manufacturability constraints be represented without hiding craft knowledge?
- What canonical design families should anchor regression tests?
- How should high-voltage safety margins enter optimization without creating false precision?

8 Conclusion

Differentiable geometry search makes falsification apparatus design systematic. The output is not a promised anomaly; it is a better set of devices for killing bad hypotheses quickly.

References

References

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