**Report: ML-based IR Drop Prediction**

**1. Features Used for Training**

**The model was trained using three primary feature maps generated from SPICE netlists and solved voltage data via Modified Nodal Analysis (MNA):**

1. **Current Map (current\_map\_<case>.csv)**
   * **Captures current distribution in the power grid.**
2. **PDN Density Map (pdn\_density\_map\_<case>.csv)**
   * **Represents power distribution network density.**
3. **Voltage Source Map (voltage\_source\_map\_<case>.csv)**
   * **Shows locations of voltage sources in the grid.**

**Label (Target):**

* **IR Drop Map (ir\_drop\_map\_<case>.csv)**
  + **Computed as *Vmax – Vnode* for each grid point.**

**2. Choice of Model and Justification**

**Two deep learning architectures were used during experimentation:**

**Baseline: U-Net**

* **Structure:**
  + **Encoder: Two convolutional layers + max pooling blocks.**
  + **Bottleneck: Dense feature extraction layer.**
  + **Decoder: Transposed convolutions for upsampling.**
* **Reason for Use:**
  + **Proven for pixel-wise prediction.**
  + **Skip connections preserve fine spatial details.**
  + **Well-suited for 2D feature maps.**

**Improved: ResUNet**

* **Enhancements:**
  + **Residual blocks for improved gradient flow.**
  + **Deeper network for learning complex patterns.**
* **Reason for Use:**
  + **Addresses vanishing gradient issues.**
  + **Captures both global context and local details.**

**3. Accuracy Improvements**

* **Data Normalization: Features/targets scaled to [0, 1], rescaled back to mV.**
* **Negative Prediction Clamping: ReLU ensures non-negative outputs.**
* **Loss Function: MSE loss + early stopping + learning rate scheduling (ReduceLROnPlateau).**
* **Training Enhancements:**
  + **Increased epochs.**
  + **Added batch normalization after convolutions.**
  + **Switched from U-Net → ResUNet for better hotspot localization.**
* **Evaluation Fixes:**
  + **Corrected F1 score calculation (hotspot = IR drop ≥ 90% of max).**
  + **Added runtime measurement for inference.**

**4. Metrics Table (Benchmarks)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Testcase** | **MAE (mV)** | **F1 (≥90% max)** | **Runtime (s)** |
| **testcase1** | **2.377** | **0.001** | **0.305** |
| **testcase11** | **3.421** | **0** | **0.148** |
| **testcase12** | **3.790** | **0** | **0.140** |
| **testcase17** | **0.441** | **0.006** | **0.139** |
| **testcase18** | **0.404** | **0.005** | **0.152** |
| **testcase2** | **3.504** | **0.001** | **0.130** |
| **testcase3** | **2.920** | **0** | **0.158** |
| **testcase4** | **3.542** | **0** | **0.132** |
| **testcase5** | **2.031** | **0.003** | **0.148** |
| **testcase6** | **3.221** | **0.001** | **0.133** |
| **Average** | **2.565** | **0.002** | **0.158** |

**5. Predicted vs Ground Truth Heatmaps**

A close-up of a graph

AI-generated content may be incorrect.**Recent comparison: MAE has improved significantly, False positives everywhere: The model predicts IR drop in areas where there should be none**

A screenshot of a graph

AI-generated content may be incorrect.

2nd update

A close-up of a graph

AI-generated content may be incorrect.

1st Iteration

**6. Training Parameters**

* **Epochs: 25–50 (increased)**
* **Learning rate: 3e-4 (optimized)**
* **Batch size: 8**
* **Alpha: 5.0–10.0 (hotspot loss weight)**
* **Optimizer: Adam + gradient clipping**

**7. Model Structure**

* **Architecture: ResUNet with residual connections**
* **Input channels: 3 (current map, PDN density map, voltage source map)**
* **Output channels: 1 (IR drop prediction)**
* **Activation: ReLU on final layer**

**8. Performance Improvements**

**Before Updates:**

* **MAE ≈ 10.0 mV**
* **F1 ≈ 0.001**
* **Scale mismatch: predictions 0–1.75V vs ground truth 0–0.004V**
* **High false positives**

**After Updates:**

* **MAE ≈ 2.6 mV (74% improvement)**
* **F1 ≈ 0.002 (still low)**
* **Predictions match ground truth scale**
* **No negative values**

**9. Technical Specifications**

* **Data Processing: 600×600 grid, 2000 DBU/μm, CSV format**
* **Model: ResUNet with skip connections**
* **Training Config: MAE + Hotspot MAE loss, ReduceLROnPlateau scheduler**
* **Device: CPU**

**10. Summary of Fixes**

1. **Architecture: Added ReLU on final output → ensures non-negative predictions.**
2. **Training Dataset: Normalized labels to 0–1, stored scaling factors, updated visualization.**
3. **Inference Pipeline: Added denormalization, debug range reporting.**
4. **Evaluation Pipeline: Consistent denormalization, correct metric calculation.**

**11. Expected Results to improve further.**

* **F1 scores should improve from 0.001 to 0.3-0.7 range**
* **MAE should decrease significantly**
* **Predictions should show proper hotspot detection with correct magnitude scaling**

**The MAE has improved significantly (from ~10mV to ~2.6mV) and the value ranges are now much closer. However, the F1 scores are still very low (0.002 average), which means the model is still not detecting hotspots effectively. False positives everywhere: The model predicts IR drop in areas where there should be none.**

* **Poor hotspot localization: The model shows some activity in the correct region but fails to accurately localize the specific hotspots**
* **Low sensitivity: The predicted hotspots are too faint and diffuse.**

**12. Remaining Challenges**

* **Hotspot Detection: F1 = 0.002 (very low)**
* **False Positives: Still predicts IR drop in non-hotspot regions**
* **Low Sensitivity: Hotspots faint/diffuse**

**False Positive Reduction**

* **Current: Widespread false positives in non-hotspot regions**
* **Target: Minimal false positives, focused hotspot predictions**
* **Issue: Model predicts IR drop where there should be none**