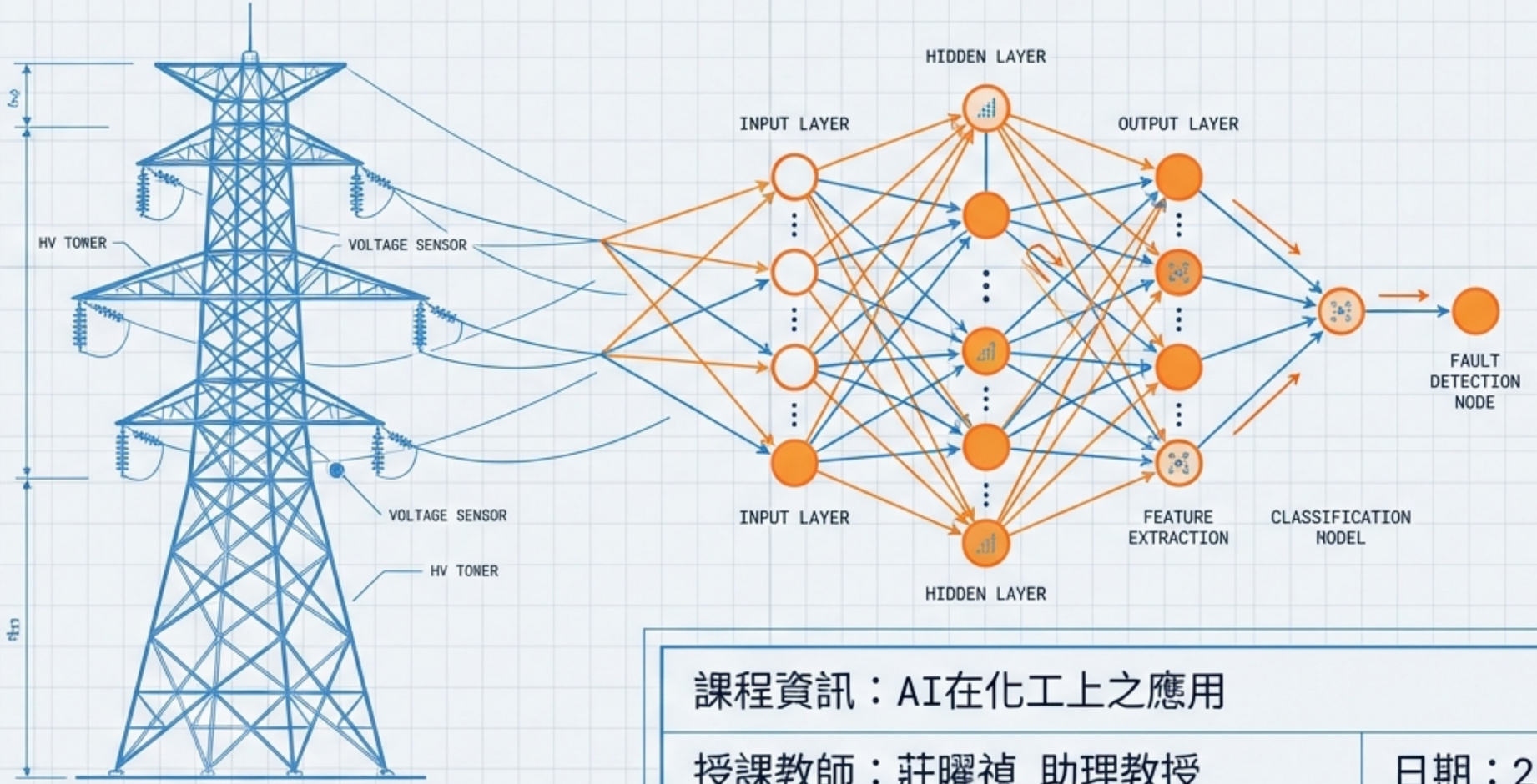
Unit 12 工業應用案例：電氣設備故障診斷與分類

結合領域知識與機器學習的工程實踐

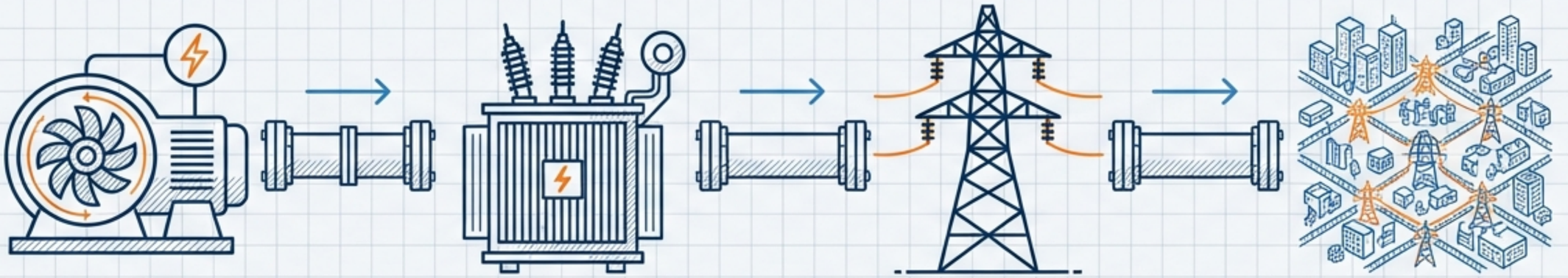


課程資訊：AI在化工上之應用

授課教師：莊曜禎 助理教授

日期：2026-01-28

任務目標：確保電網系統穩定性



發電機
(Generator)

變壓器
(Transformer)

輸電線
(Transmission Line)

電網
(Grid)

Technical Specification

快速響應 (Speed)

- 必須在毫秒級內檢測故障並啟動保護設備

Technical Specification

系統穩定 (Stability)

- 正確分類故障以防止連鎖反應與大規模停電

Technical Specification

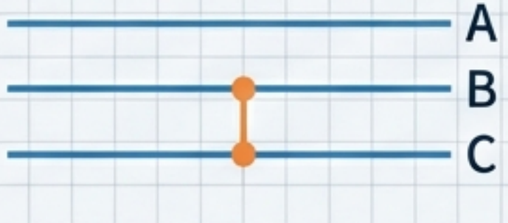
複雜性 (Complexity)

- 需在動態擾動下準確區分多種故障類型

解碼故障類型：六種系統狀態

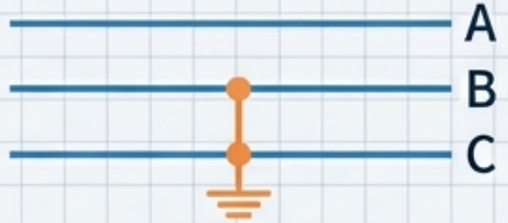
LG (單線對地)

[1, 0, 0, 1]



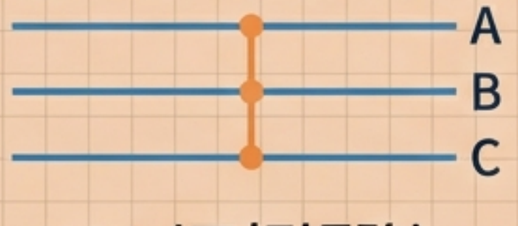
LL (線對線)

[0, 0, 1, 1]



LLG (雙線對地)

[1, 0, 1, 1]

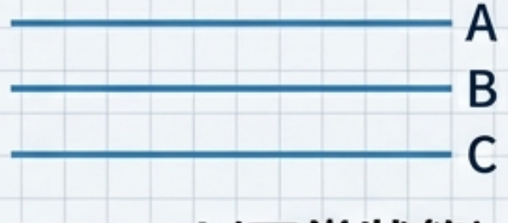


LLL (三相短路)

[0, 1, 1, 1]

LLLG (三相對地)

[1, 1, 1, 1]

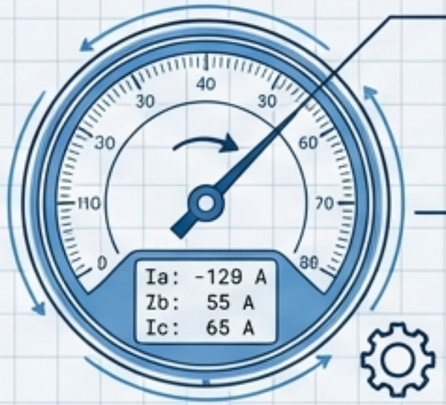


Normal (正常狀態)

[0, 0, 0, 0]

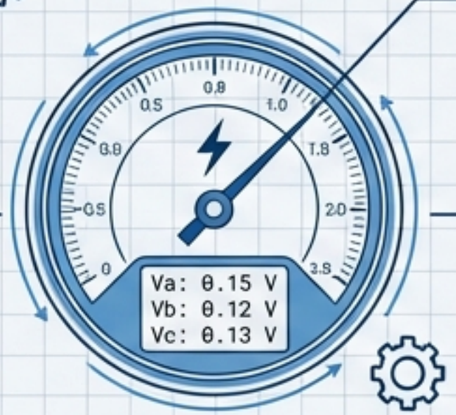
原始素材：傳感器數據與特徵

輸入特徵 (Input Features)



電流 (Current)

-65θ to +85 A



電壓 (Voltage)

-θ.27 to +θ.40 V

數據集規格 (Dataset Specs)

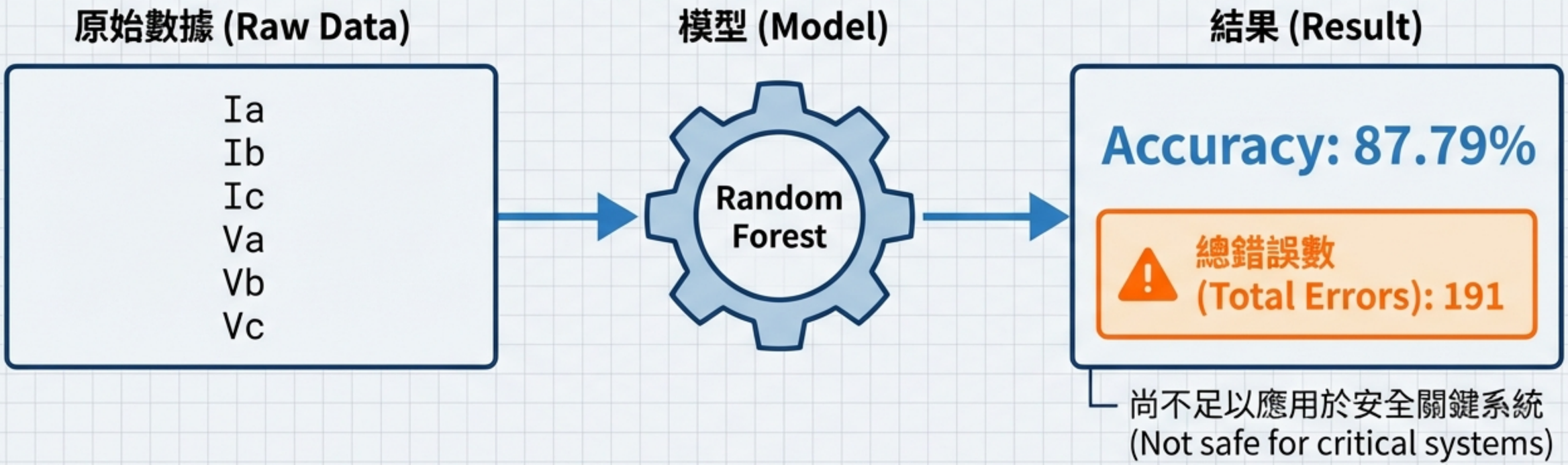
總樣本數 (Total Samples): 7,861

缺失值 (Missing Values): None

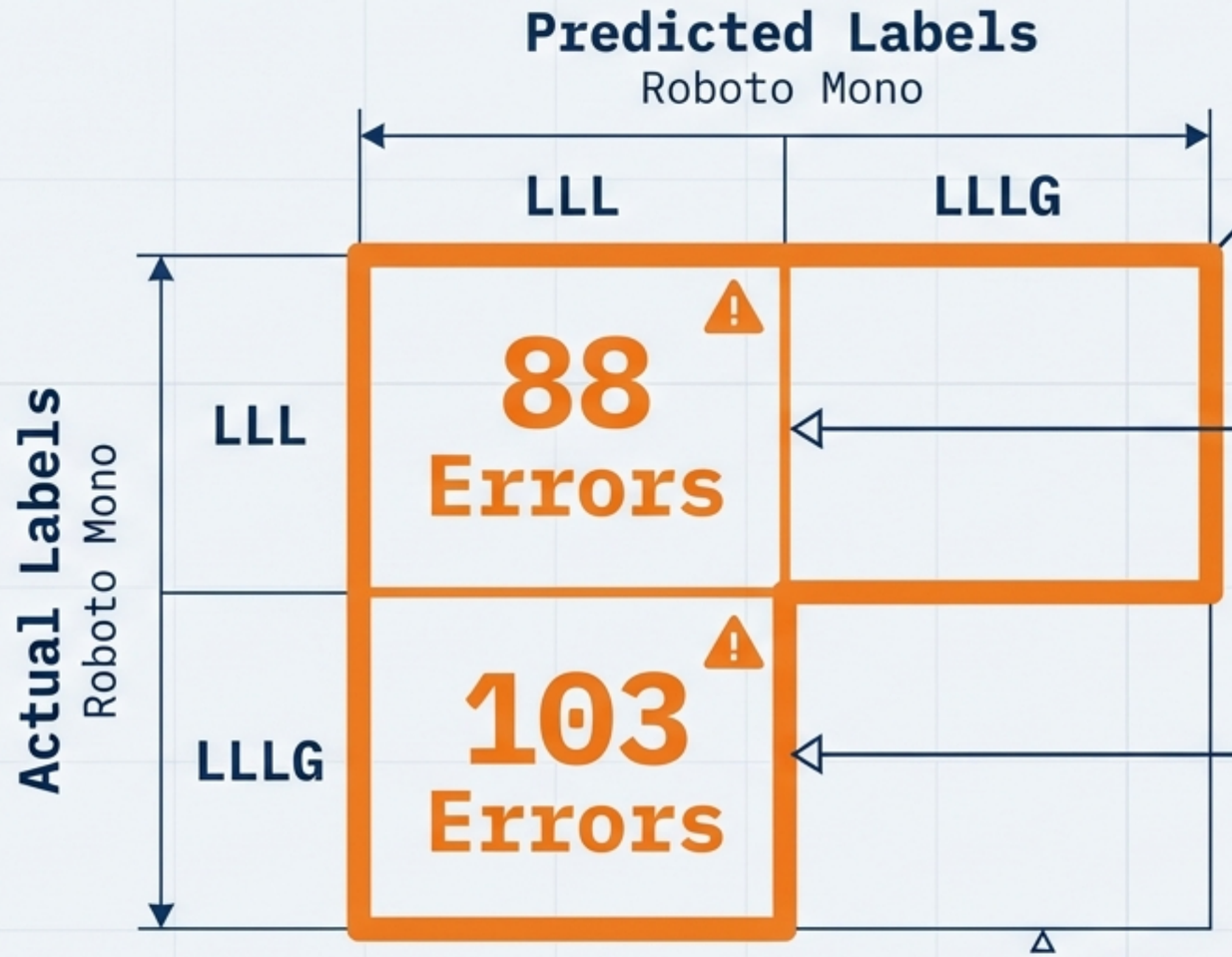
類別分佈: LG (30%), Others (~14%)

關鍵問題：僅靠這6個原始讀數，能否準確區分所有故障？

實驗一：基準模型測試



故障分析：模型為何失敗？

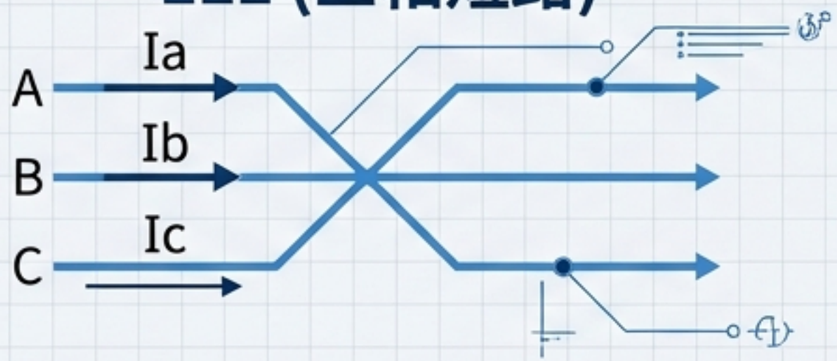


- **盲點** (Blind Spot)：原始特徵無法有效反映「接地 (Ground)」的存在。
- **原因** (Reason)：LLL 與 LLLG 波形極其相似。
- **後果** (Consequence)：安全隱患與經濟損失。⚠

物理洞察：引入零序分量

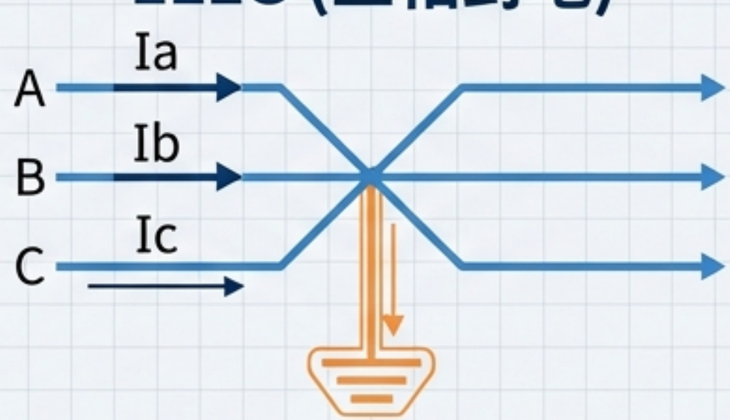
$$I_0 = (Ia + Ib + Ic) / 3$$

LLL (三相短路)



系統平衡 (Balanced) → $I_0 \approx 0$

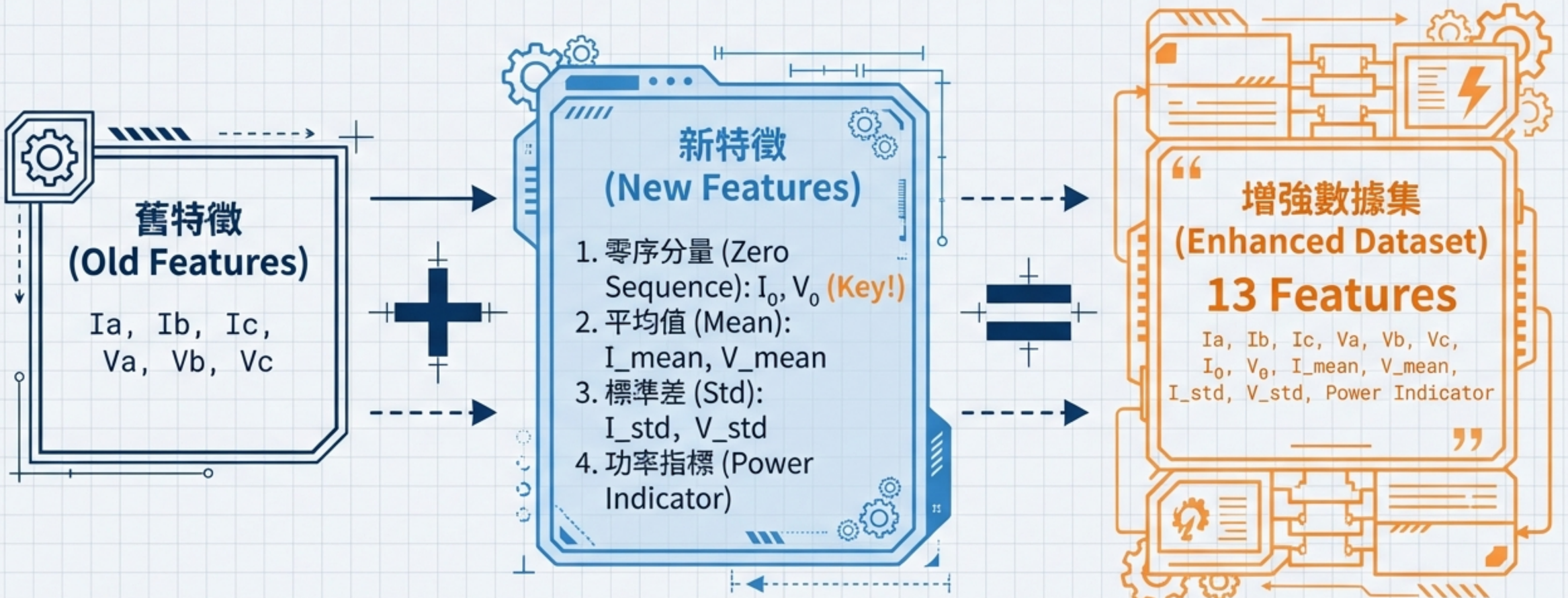
LLLG (三相對地)



存在接地路徑 (Ground Path) → $I_0 \gg 0$

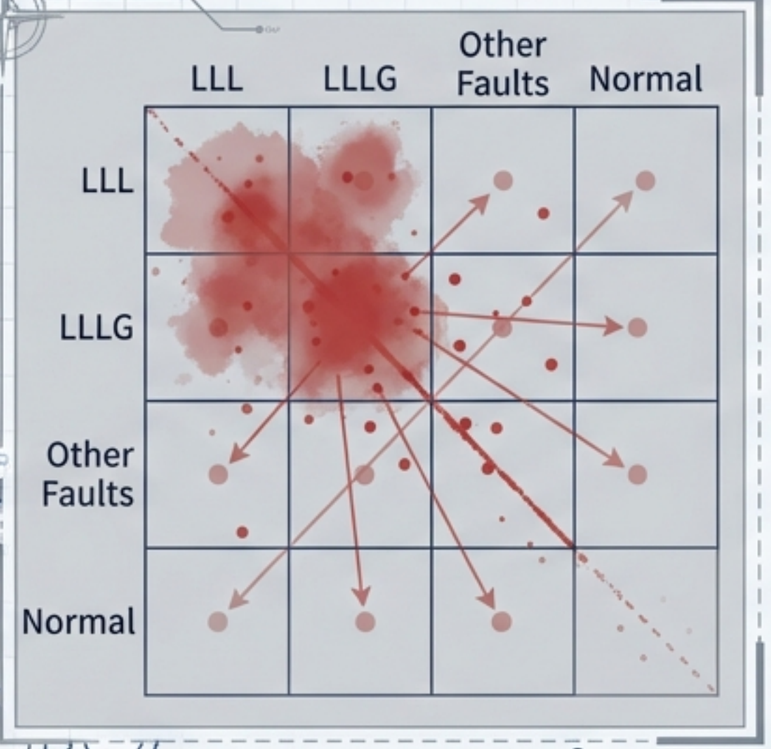
我們不需要更複雜的模型，我們需要物理特徵。

特徵工程策略：數據升級

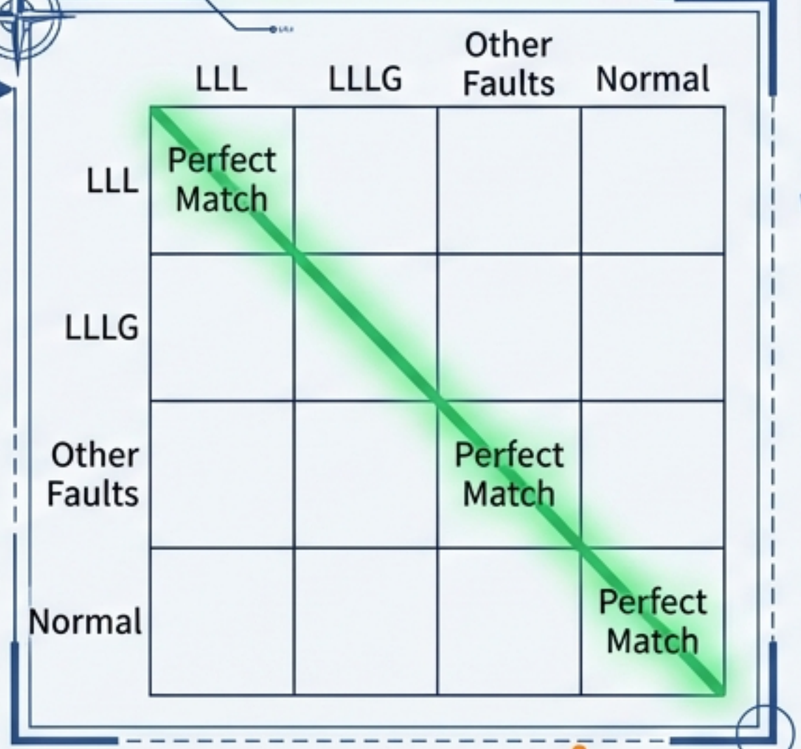


實驗二：突破性的完美分類

Experiment 1



Experiment 2



Result Box

準確率 (Accuracy)：

100.00%

LLL/LLLG 錯誤數：

0

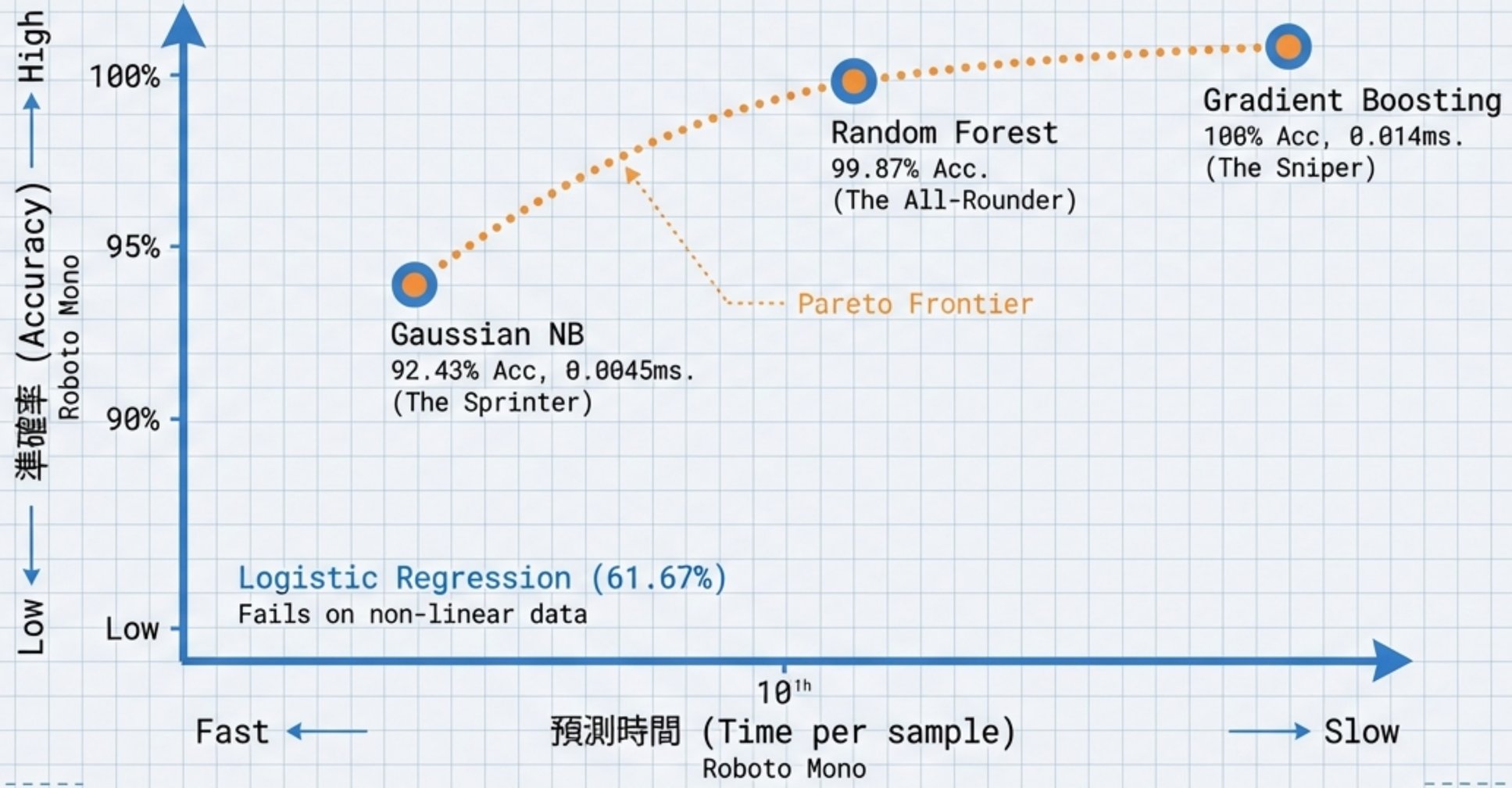
改善幅度 (Improvement)：

+12.21%

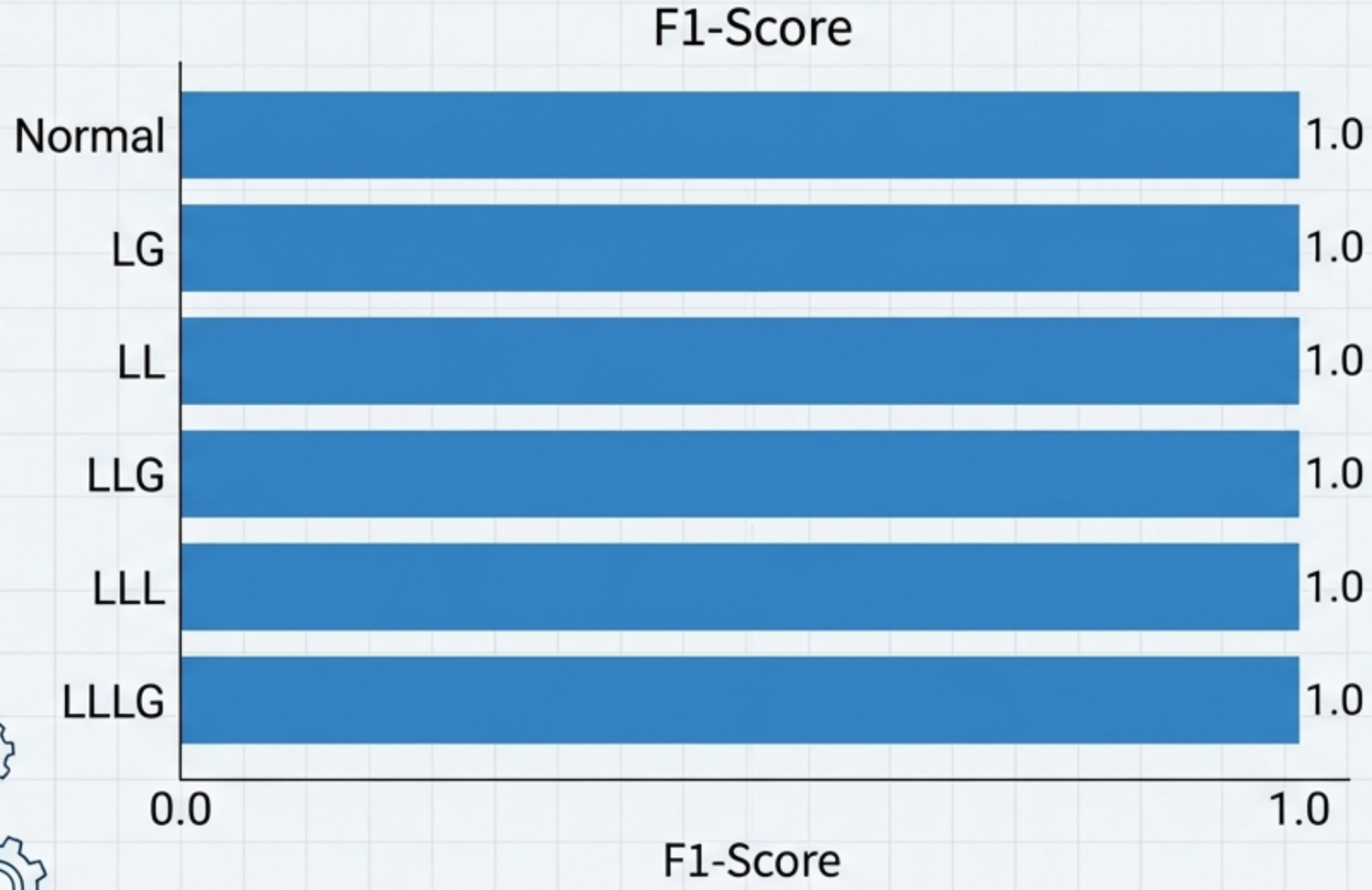
零序特徵完全解決了混淆問題

Industrial Blueprint v1

模型競技場：速度與準確率的權衡



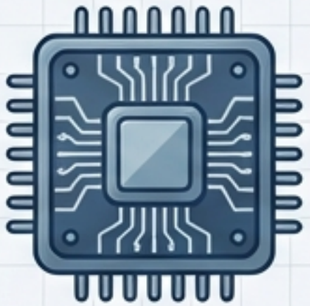
詳細性能指標 (Detailed Performance Metrics)



- Precision (精確率): 1.0 (無誤報 Zero False Alarms)
- Recall (召回率): 1.0 (無漏檢 Zero Missed Faults)
- Support: ~200-400 samples per class

工業部署策略 (Industrial Deployment Strategy)

邊緣設備 (Edge Device)



Model: Decision Tree
Task: 快速切斷 (<1ms)

實時監控 (Real-time Monitoring)

Model: Gaussian NB
Task: 趨勢分析

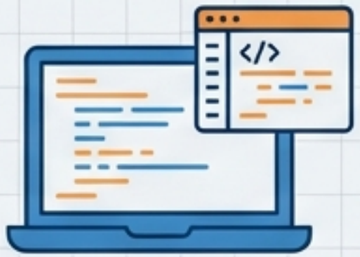
深度分析 (Deep Forensics)

Model: Gradient Boosting
Task: 根因分析 (100% Acc)

總結與關鍵發現 (Summary & Key Takeaways)

下一步與延伸閱讀 (Next Steps & References)

動手實作



復現實驗代碼
(Reproduce Code)
嘗試實作階層式監控系統

參考文獻

Kaggle Dataset: Electrical Fault Detection

IEEE Standards for Power System Protection

SMOTE Technique

思考

"Domain knowledge transforms raw data into actionable intelligence."