DefectGPT: Towards Multi-Class Defect Detection with Limited Electrical Samples

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Summary

We propose a novel **Multimodal Large Language Model (MLLM)**-based solution for multi-class electrical defect detection with limited electrical image samples.

Theory

Few-shot Learning: $\mathcal{F}_{\text{FSL}}(\mathbf{q}) = \text{Attn}(\mathbf{V}, \mathbf{K}, \mathbf{q}) \approx \underbrace{\mathbf{W}_V \mathbf{X}' (\mathbf{W}_K \mathbf{X}')^\top}_{\text{Few-shot kernel}} \mathbf{q}$

Hypothesis-First Learning (HFL):

$$\tilde{F}_{\text{HFL}}(\mathbf{q}) = \Big(\underbrace{\mathbf{W}_{\text{FSL}}}_{\text{Few-shot kernel}} + \underbrace{\sum_i (\mathbf{W}_V \mathbf{d}_i) \otimes (\mathbf{W}_K \mathbf{d}_i)}_{\text{Descriptions (where } \mathbf{d}_i \text{ is a token)}} + \underbrace{\sum_i (\mathbf{W}_V \mathbf{r}_i) \otimes (\mathbf{W}_K \mathbf{r}_i)}_{\text{Self-reflections (where } \mathbf{r}_i \text{ is a token)}} \Big) \mathbf{q}$$

$$\text{Update Matrix } \Delta \mathbf{W}_{\text{HFL}}$$

HFL performs an **implicit, on-the-fly parameter adaptation.**

Motivation

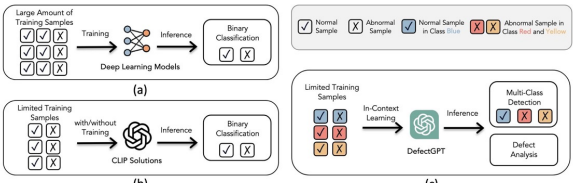

Fig. 1: Different paradigms for anomaly detection.

Semiconductor industry is a vital global sector and had **$500B+** revenue in 2024.

🔎 Challenges in Electrical Defect Detection

- Limited Samples
- Non-visual defects
- Requires non-destructive methods

Methodology

How can MLLMs learn effective defect patterns in a few-shot manner?

By using Defect Description Generation and Hypothesis-First Learning (HFL)!

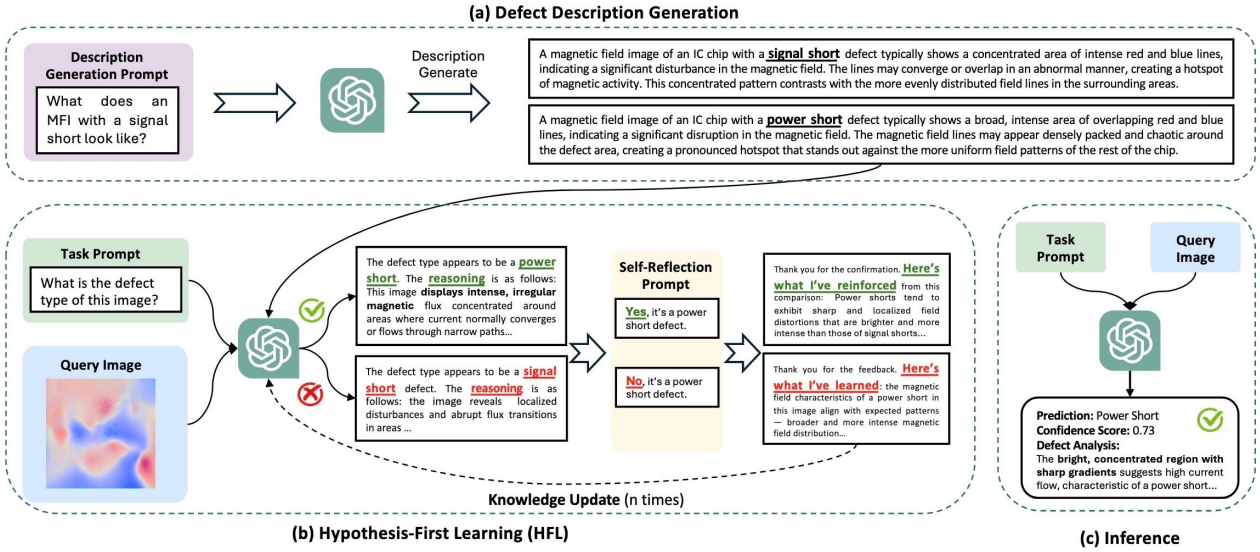

Fig. 2: An overview of DefectGPT.

Results

Methods	MFI				WaferMap			
	Top-1 Acc.	AUPR	Macro-F1	Micro-F1	Top-1 Acc.	AUPR	Macro-F1	Micro-F1
CLIP	50.00	54.43	33.33	50.00	30.33	73.05	19.19	30.33
CuPL	60.00	60.93	52.38	60.00	30.22	71.35	18.75	30.22
LLaVA	52.50	53.37	42.03	52.50	12.90	50.25	8.16	12.90
Phi-3.5 (ZSL)	45.00	48.50	37.32	45.00	11.11	51.86	2.22	11.11
Phi-3.5 (FSL)	60.00	52.19	52.38	60.00	11.11	50.00	2.22	11.11
GPT-4o (ZSL)	61.67	52.00	61.67	59.11	20.70	50.84	12.14	20.70
GPT-4o (FSL)	82.50	88.87	82.21	82.50	48.78	66.75	48.33	48.78
DefectGPT	**97.50**	**95.67**	**97.49**	**97.50**	**67.11**	**92.16**	**62.52**	**67.11**
Improvement	18.18%	7.65%	18.59%	18.18%	37.58%	38.07%	29.36%	37.58%

Table1: Performance comparison on two electrical datasets.

Key Takeaway

🚀 DefectGPT performs multi-class defect detection with limited amounts of data (i.e., 1-3 samples), including non-visual defects.

⭐HFL iteratively refines descriptions into precise, discriminative forms, which can be used to enhance the capabilities of existing MLLMs.

💎Theoretical analysis of HFL and ablation studies of defect description are provided, showing the effectiveness of combining both modules.