Hybrid Approach Report: Automated Hotspot Segmentation for Airflow Leakage

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July 2, 2025

Objective

To implement and evaluate the proposed hybrid pipeline that uses temporal analysis to automatically generate prompts for the Segment Anything Model (SAM), with the goal of achieving robust, automated segmentation of two distinct airflow leakage spots from IR videos.

1. Methodology: The Hybrid Approach

Following the preliminary analysis, a new automated pipeline was developed. The workflow is as follows:

1. **Activity Map Generation:** For each input video, a temporal slope analysis is performed across all frames to generate a 2D `activity_map`, where pixel intensity corresponds to the rate of temperature change.

2. **Candidate Detection & Filtering:** All active regions in the map are identified using thresholding and connected components. These candidates are then filtered based on shape properties (minimum area, aspect ratio) to discard obvious non-leak artifacts like edge lines.

3. **Robust Prompt Selection:** The surviving candidates are scored using a weighted metric that combines their peak activity, solidity (shape compactness), and spatial isolation (distance from other candidates). The centroids of the top two highest-scoring candidates are selected as the final automatic prompts.

4. **Prompted SAM Segmentation:** A representative frame from the video (median) is provided to SAM. The automatically generated positive prompts, along with programmatically generated negative prompts in the immediate vicinity, are used to guide SAM to produce a precise, final segmentation mask for each leak.

2. Results

The automated hybrid pipeline was executed on the full dataset of 12 two-hole videos.

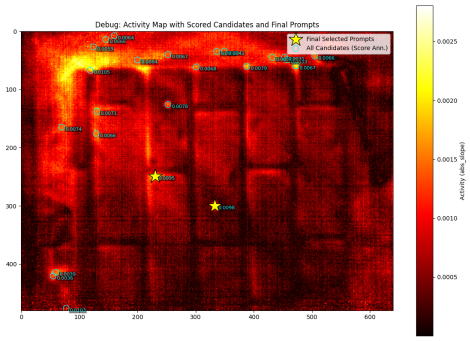
2.1. Successful Cases (10 out of 12 videos)

The pipeline successfully identified and accurately segmented the two true leak locations in the majority of cases. The multi-stage filtering and scoring mechanism proved effective at distinguishing the blob-like, isolated true leaks from the more irregular and clustered edge artifacts. The full set of output visualizations is included in the accompanying zip file.

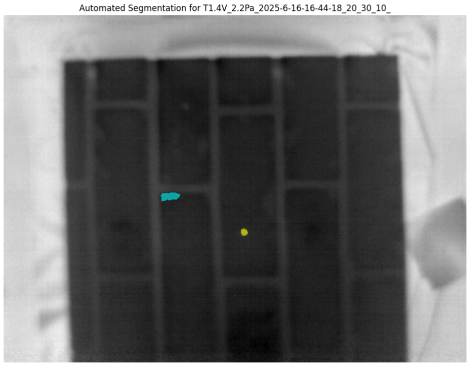
2.2. Failure Case Analysis (2 out of 12 videos)

The two failures highlight a remaining challenge that arises when videos exhibit extremely high thermal contrast and noisy activity along structural edges (e.g., the top border of the brick panel).

Interpretation of Failure: In these specific cases, the activity (slope magnitude) of the edge artifacts is so overwhelmingly high that even after applying the shape and isolation scoring, their `final_score` still surpasses that of the true, but weaker, leak signals. The algorithm correctly identifies the two "most active" plausible blobs, but those happen to be on the noisy edges rather than at the true leak locations, as detailed in Figure 1 and Figure 2.

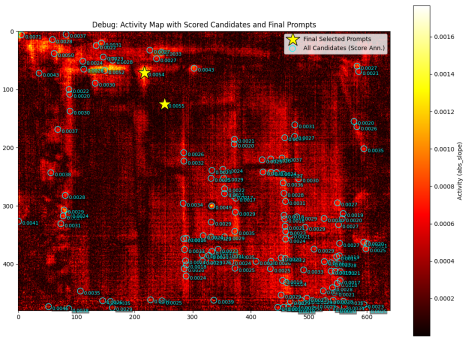


(a) Debug plot for the first failing case. The final prompts (yellow stars) are incorrectly placed on high-activity edge artifacts.

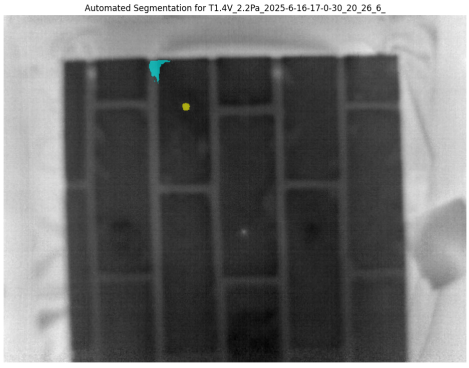


(b) Final segmentation result. SAM correctly segments the objects at the incorrect prompt locations, masking the edges.

Figure 1: Analysis of Failure Case 1.



(a) Debug plot for the second failing case. Again, the prompt selection is drawn to high-activity vertical and horizontal structural lines.



(b) Final segmentation result, where SAM has correctly segmented the line-like artifacts it was prompted with.

Figure 2: Analysis of Failure Case 2.

Conclusion

The hybrid approach represents a significant step forward, achieving a high success rate (10/12) in fully automated segmentation. The current failure mode is well-understood and stems from extreme signal-to-noise ratio issues where structural artifacts overwhelm the true leak signal.

The immediate next step is to further enhance the robustness of the prompt-finding algorithm by incorporating pre-processing techniques directly on the activity map before candidate detection. The most promising technique I found is **morphological background subtraction**, which is specifically designed to suppress large, low-frequency artifacts (like the bright edges) and make smaller, sharper peaks (the true leaks) stand out. This should directly address the observed failure mode.